MOTOROLA'S INTERFERENCE TECHNICAL APPENDIX

1 INTRODUCTION

With the advent of cellular type system deployments in the 800 MHz band and the future 700 MHz band, system operators are faced with having to create highly reliable communications for noise limited systems while interference limited systems are interspersed in the design service area. At this time we are seeing an increasing number of subscriber coverage holes when the radios are in close proximity to high density SMR or cellular base station sites. As more and more radio systems are fielded with varying channel bandwidths and different types of modulation, the prevention, identification and remediation of interference is increasingly important.

- With the newer digital radio systems, interference is often reported as a loss of coverage or no coverage in areas where good coverage was predicted.
- With analog radios, the interference often audibly manifests itself, making the identification somewhat easier.
- Interference can be intermittent or constant. Intermittent interference is more difficult to identify and remedy due to its inconsistent appearance.
- Trunking systems make this more difficult as often interference is for a specific channel and that channel may or may not be assigned while the interference mechanism is active. When the trunking system's control channel is interfered with, system access and Grade of Service on alternate system resources may be affected.
- For data systems, interference from other systems may cause increased loading and response times due to the additional retires, and may affect subscriber roaming.
- The introduction of new radio systems in an existing coverage area may cause a critical point to be reached and suddenly cause degradation of system performance or complete loss of coverage in specific areas.

The purpose of this document is to sensitize system designers and maintenance personnel to these issues. First, there is a review of how the history of various band plans and hardware changes have increased the probability of interference. Next, the various mechanisms that can produce interference are defined. Common scenarios are provided to aid in identification of interference. The document closes with recommendations of hardware, procedures and actions that can greatly reduce the probability of interference both initially and in the future.

2 BACKGROUND

2.1 BAND STRUCTURE

In the early days of Land Mobile Radio there was only Low Band (25 - 50 MHz) followed later by High Band (132 - 174 MHz). The use of mobile relay (repeater) operation was quite restricted in low band, and simplex operation was the most common configuration. Simplex operation creates a higher potential for base station to base station interference, even with large physical separation. To prevent this type of interference, many systems went to two-frequency simplex, transmitting on one frequency while receiving on a second frequency. This minimizes the base-to-base interference, but prevents mobile units from being able to monitor the channel for activity prior to transmitting. This requires a highly disciplined system, as a dispatcher is the only one that can relay messages between mobile units. Unfortunately, because the mobile units can't monitor the channel before transmitting, they cause intra system interference when more than one radio at a time contends for the channel.

High band operation had more opportunities for mobile relay operation. Unfortunately the band wasn't developed in a standardized fashion. Over time this resulted in mobile relay operation with some systems using reversed frequency plans relative to the other systems. This mixed with various combinations of "close and wide spaced" mobile relay configurations made frequency coordination and interference prevention a difficult process. In fact, before the introduction of the higher frequency bands, much of the system engineering involved designing sites to accommodate the nearly incompatible frequencies and configurations.

The UHF, 450 - 470 MHz, band was an opportunity to organize the new spectrum and prevent many of the problems systemic to the older bands. However at that time the state of the art for mobile and portable transmitter bandwidth was around 6 MHz. So it was decided to organize the band in such a manner that mobile relay systems would be quite common and that mobile radios could switch to the base station transmit frequency and talk directly to another mobile radio in close proximity (talk-around). This allows radios that are out of range of the repeater to still communicate in a simplex mode on the base station talk-out frequency. The protocol was quite simple. The first mobile to transmit would simply switch to the talk-around mode and transmit. The other mobile was already monitoring the correct frequency so the initiating mobile would simply tell the receiving mobile to switch to talk-around. Once accomplished, they could communicate in a simplex mode. No matter what they did, they were always monitoring the base talk-out frequency.

To facilitate this, the band was organized into four 5 MHz blocks with three interfaces between base transmitters and mobile transmitters. Figure 1 shows how the band was organized.

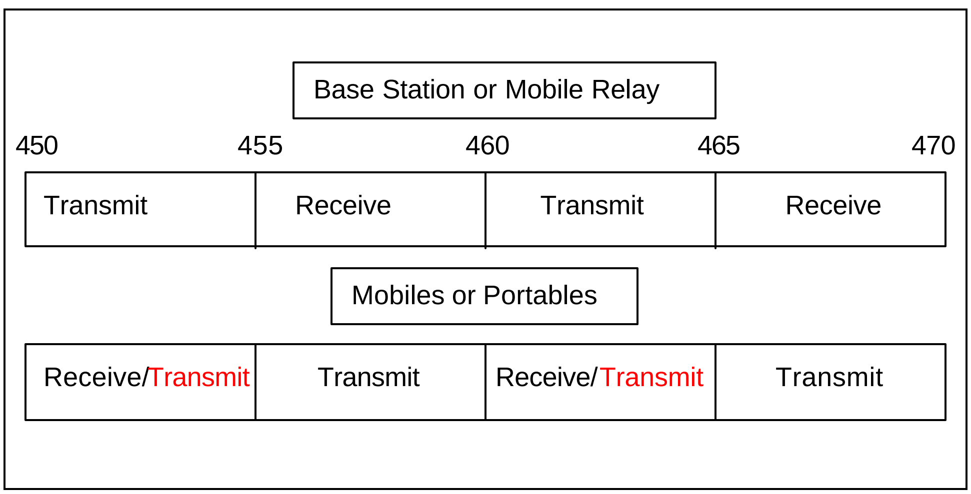


Figure 1 450 MHz Band

Later the UHF band was expanded to include sharing with UHF TV channels 14 through 20 (470 MHz - 512 MHz) in the top 13 US markets. Initially, the top ten markets got 2 TV channels each while the next three received a single TV channel. There have been additional allocations for Public Safety in Los Angeles, and some Canadian border issues preclude deployment. See CFR 47 §90.303 for specifics. To handle the different blocks of spectrum, each TV channel's band was divided in half, with land mobile base transmitters on the low half and base receivers on the high half. As a result the transmitter to receiver spacing is only 3 MHz in this portion of the band.

The next band to be allocated was the "take back" of UHF TV channels 70 - 83. This created large amounts of spectrum for private land mobile systems and for the new cellular industry. Once again, lessons from the older bands were incorporated to minimize interference potential. Transmitter/Receiver spacing was standardized at 45 MHz. To minimize the cost of subscriber units, the band was inverted from the 450 MHz band with the subscriber units transmitting on the low portion of the band.

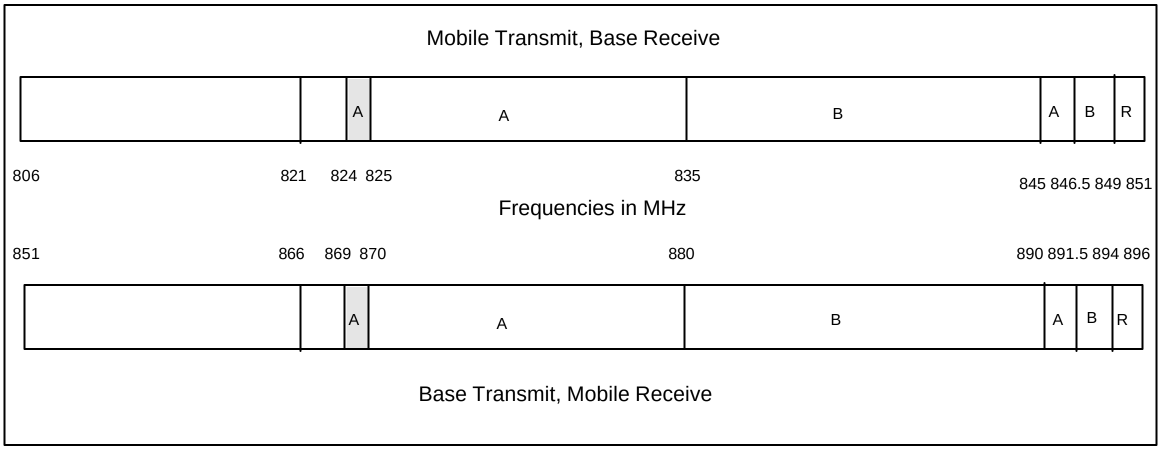


Figure 2 800 MHz Band

For trunked systems, channel assignments were made in blocks of up to five, with a constant 1 MHz separation between channels. This allowed for easy transmitter combining and minimizes some potential intermodulation. The cellular band was immediately adjacent to the land mobile band. Some reserve channels were held and later allocated to public safety and expansion of the cellular frequencies.

Later, around 1988, additional 800 MHz channels were made available exclusively for Public Safety. These new frequencies are often referred to as “821 MHz” rather than the more accurate but complex name 821-824/866-869 MHz bands. Five interoperable channels were assigned on a national basis. At that time, narrow banding to 12.5 kHz channels was difficult and operability with the existing 800 MHz channels was a requirement, so a compromise solution was developed. The channels would be 25 kHz wide, but channel assignments would be granted every 12.5 kHz. Interference would be administratively controlled by a group of Regional Frequency Coordinators. The assumption is that a receiver would provide 20 dB ACIPR and this would be considered a requirement by the frequency coordinators, but not by the FCC. Co channel frequency reuse was generally based on a 35 dB C/I, but local regional frequency planning committees policies may alter this requirement slightly. Local planning committee recommendations must be adhered to.

The last block of frequencies allocated to private land mobile is in the 900 MHz band. This was the first real narrowband allocation. Channels are 12.5 kHz wide. This creates the potential for “near-far” interference scenarios.

The “near-far” situation has two different scenarios, as shown in Figure 3.

- A unit close (near) to a site on a nearby or adjacent undesired channel interferes with a weak (far) unit talking inbound on the desired channel.
- A unit far from its desired site is interfered with when close (near) to a nearby or adjacent undesired channel base.

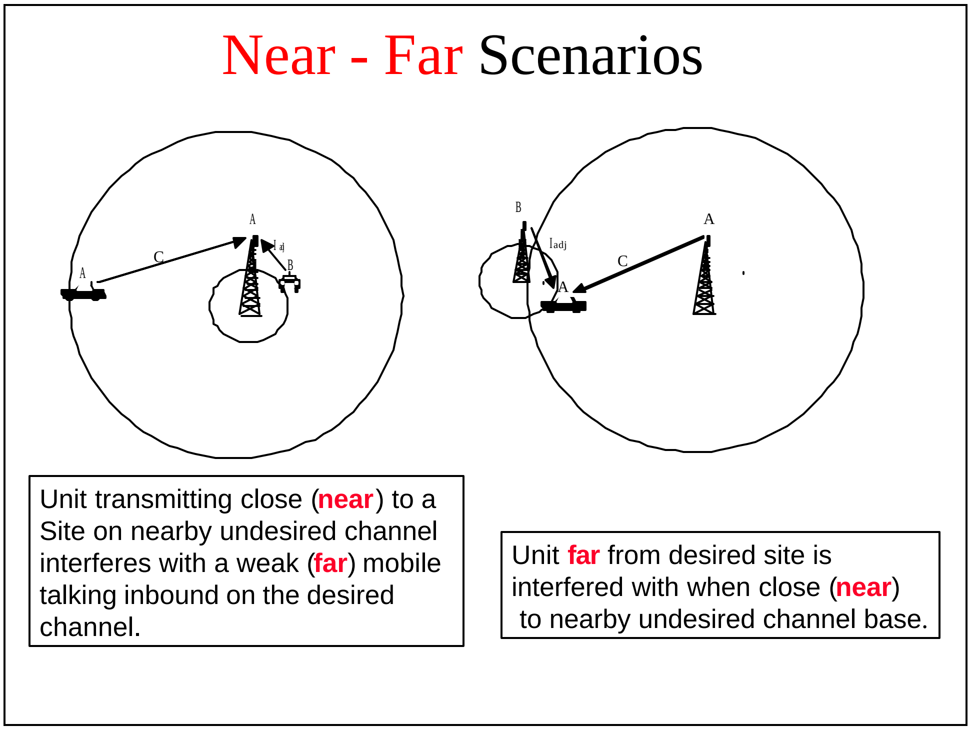


Figure 3 Near - Far Scenarios

To compensate for this possibility, the channels were allocated in blocks of 10 adjacent channels. The concept was that any money spent to be a "good neighbor" should result in improved system performance for the person that spent the money. Thus this assignment policy created the situation where a users adjacent channel assignment belonged to themselves, except for the two end channels of a block.

Channels were assigned with a transmit to receive separation of 39 MHz with the same configuration as 800 MHz, base stations transmit on the high split, and mobiles transmit on the lower split. This minimizes the cost of power transistors for the subscriber units as they operate on the lower frequencies.

2.2 HARDWARE HISTORY

Older radios used crystals or channel elements to derive its transmit and local oscillator frequencies. As a result, if a radio had four-frequency capability, it had to have a total of eight crystals or channel elements to generate the correct frequency sources. This resulted in considerable cost and space being devoted for just the frequency generation.

Crystals are a very high Q component, ~50,000, so they generate a very clean response. To stabilize their performance, heated ovens were used to keep the crystals at a constant temperature. This was a considerable current drain, even in mobiles. As greater frequency stability was required the channel element became the preferred solution. A channel element is a crystal with a temperature compensating circuit that has been calibrated for that specific crystal, thereby eliminating the requirement for heating and its current drain .

The channel element eliminated the current drain that was had been necessary to provide the temperature stability. However, they were still large and made radios quite large. The next step was to eliminate some of the channel elements by providing an offset oscillator for the receive frequency. In bands where a constant frequency difference from transmitter to receiver exists, one oscillator can be used for the specific transmit oscillator and offset it in frequency to become that pairs associated receiver local oscillator. When talk-around operation was needed, a second offset oscillator was optionally available. Thus a normal 4-frequency radio would have 4 channel elements and one offset oscillator. When equipped with Wide Space Transmit, it would have 4 channel elements and two offset oscillators. Note that the frequency stability was decreased by the additional frequency error of the offset oscillator.

The channel element size limitation allowed receivers to be designed with relatively narrow bandwidths. As a result, helical resonators were commonly used in receiver preselectors. They provided good front-end selectivity, which provided excellent protection from undesired signals. However the next step in providing increased frequency capabilities required more flexibility, which resulted in the replacement of the highly selective front-end with one with a greater bandwidth.

The frequency synthesizer was introduced in the early 1980's. The frequency synthesizer is a lower Q device, and only requires a single channel element at its fundamental frequency. The instructions for the synthesizer to be able to generate the appropriate frequencies are stored in a memory module that could be a PROM or code-plug.

A frequency synthesizer costs more than separate channel elements until a critical number of channels is reached. Radios were introduced with more memory to hold the additional instructions and user interfaces were developed to allow the users to keep track of what channels they are on.

To be able to use the increased frequency capability, radios had to have increased bandwidth. Transmitters were widened, as were receivers. Some representative values from that era are shown below in Figure 4.

Radio Type	Transmitter BW (MHz)	Receiver BW (MHz)
High Band Mocom 70	1, 2 w/ center tuned[1]	2
UHF Mocom 70	5	1
High Band Syntor	12	2
UHF Syntor	10	2
High Band Syntor X	24	24
800 MHz Syntor X	19	19
High Band MCX100	26/28[2]	4/12[3]
High Band MX300S	6	2
UHF MX300S	12	2

Figure 4 1980 Era Radio Frequency Limitations

[1] A special channel element was used to tune at the average frequency of the highest and lowest frequency.
[2] Low portion of band / high portion of the band
[3] Dual front ends. Two at 4 MHz each, with 12 MHz separation.

3 INTERFERENCE MECHANISMS

There are a large number of different interference mechanisms that can cause a radio to have degraded performance. To properly determine the root cause or predominant mechanism, field measurements are normally required. By the proper introduction of a step attenuator and/or cavity filter in the receiver's lineup or cavities into the suspect transmitter's lineup, the effect can be measured and from that the root cause determined.

There are several important reference standards that should be considered in making measurements of interference. They are all published by the TIA/EIA:

1. TIA/EIA-603 "Land Mobile FM or PM Measurement and Performance Standards."
2. TIA/EIA/IS-102.CAAA, "Digital C4FM/CQPSK Transceiver Measurement Methods"
3. TIA/EIA/IS-102.CAAB, "Digital C4FM/CQPSK Transceiver Performance Recommendations."
4. TIA/EIA/TSB-88A, "Wireless Communications Systems – Performance in Noise and Interference-Limited Situations – Recommended Methods for Technology-Independent Modeling, Simulation, and Verification."

The following mechanisms are the most common and will be discussed as well as recommended methods of measurement.

- Receiver Desensitization
  - ACRR - Adjacent Channel Rejection Ratio
  - ACCPR - Adjacent Channel Coupled Power Ratio
  - ACIPR - Adjacent Channel Interference Power Ratio
  - Overload
  - Local Oscillator
    - Sideband Noise
    - Radiation
  - Spurious Responses
- Intermodulation (IM)
  - Receiver
  - Transmitter
  - External
- Transmitter
  - Sideband Noise (adjacent/alternate channels)
  - OOB Emissions (>250% of channel bandwidth)
  - Spurious Emissions (Discrete frequencies)

4 EFFECTIVE RECEIVER SENSITIVITY

Receiver Desensitization occurs when a receiver requires higher signal levels to provide the same performance as when the interference source isn't present. The result is referred to as "Effective Receiver Sensitivity" as it determines what the sensitivity is in the presence of the interference mechanism and compares that to the sensitivity of a receiver when using only a signal generator, eliminating all external sources of interference. The difference between the Effective Sensitivity and the Normal Sensitivity is call Desensitization.

The Effective Receiver Sensitivity method of measurement is shown in Figure 5.

1. Measure and record the reference sensitivity of the receiver. The reference sensitivity is typically 12 dB SINAD for analog receivers or 5% static BER for digital receivers.

2. The receiver under test is connected to an “iso-tee” or directional coupler. Through the isolated leg, a signal generator is connected and the main input leg is terminated in the correct impedance (50Ω).
3. The receiver’s reference sensitivity is again measured and recorded.
4. The termination is removed and the input port is connected to the normal external antenna system.
5. The signal generator is increased until the reference sensitivity is once again achieved and the value recorded.

The Effective Sensitivity is determined by determining the increase in required signal level to regain the performance provided at the reference sensitivity [Cs/N]. In this case the Cs/N is now Cs/(I+N).

$$\textit{Effective Sensitivity} = \textit{Direct Reference Sensitivity (Step 1) x } \frac{\text{Sensitivity(Step5)}}{\text{Sensitivity(Step3)}}$$

For example, if the direct reference sensitivity is -119 dBm and the value in steps 3 and 5 are -99 dBm and -80 dBm then the effective sensitivity is -119 dBm + (-80 -(-99)) = -100 dBm, or 19 dB of desensitization.

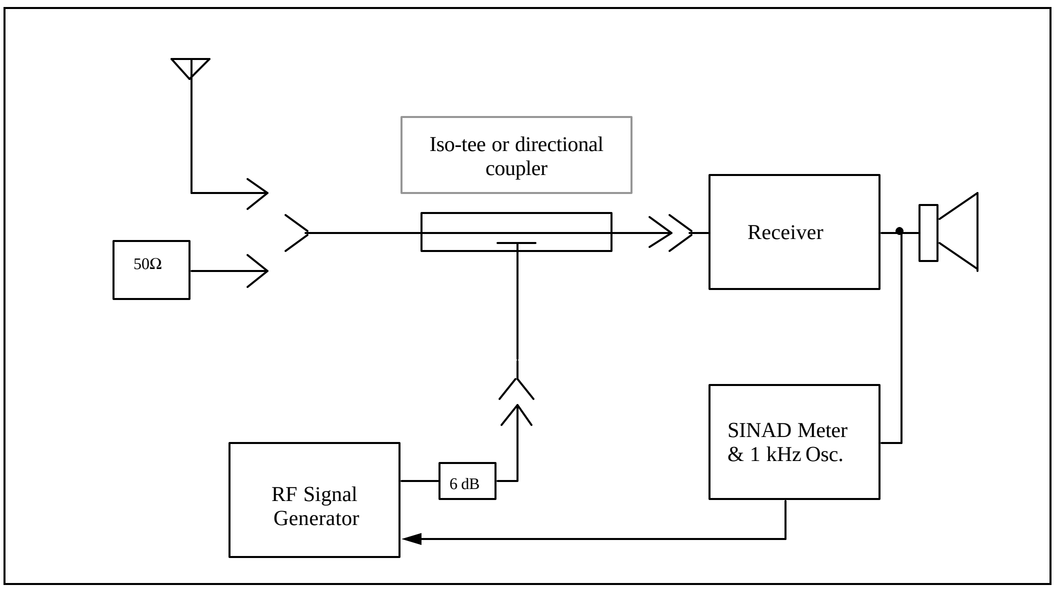


Figure 5 Receiver Desensitization Measurement

4.1 RECEIVER INTERFERENCE MEASUREMENT THEORY

Some receiver specifications are only valid when the desired signal is at reference sensitivity. When the desired is at this weak signal level, the noise floor becomes part of the consideration. As a result, it is commonly measured by injecting a desired signal into a receiver at its reference sensitivity and then boosting the desired signal by 3 dB. The potential interference is introduced and increased in level so that the original reference sensitivity is regained. This is essentially causing the interference to produce the same effect as the thermal noise floor of the receiver. The two noise floors add up to 3 dB greater than the original noise floor. Then the effect of the interference is equivalent to an on-frequency interferer reduced by the difference between the original reference sensitivity and the level of the interferer.

As will be shown later, when the desired signal is considerably above the reference sensitivity, the 3 dB boost is no longer required.

4.1.1 Receiver Overload

When a receiver is exposed to very strong signal levels, enough undesired energy could potentially force its way past the selectivity elements to cause limiters or AGC circuits to be activated. This reduces the available gain for the desired signal resulting in a loss of sensitivity. Figure 6 represents a “typical” receiver. It is general enough so it can be used for most of the receiver examples.

In this case, a strong signal passes easily through the preselector and is amplified and then down converted in frequency. The Intermediate Frequency Filters reduce the amplitude of the desired signal in addition to filtering the undesired signals. Typically its amplified again and then filtered again. Some receivers have two Local Oscillators. This is not always the case, but for the “typical” case it is included. When two Local Oscillators are being used, there is typically additional filtering at the second IF frequency. In most modern receivers, this filtering is done with Digital Signal Processors (DSP).

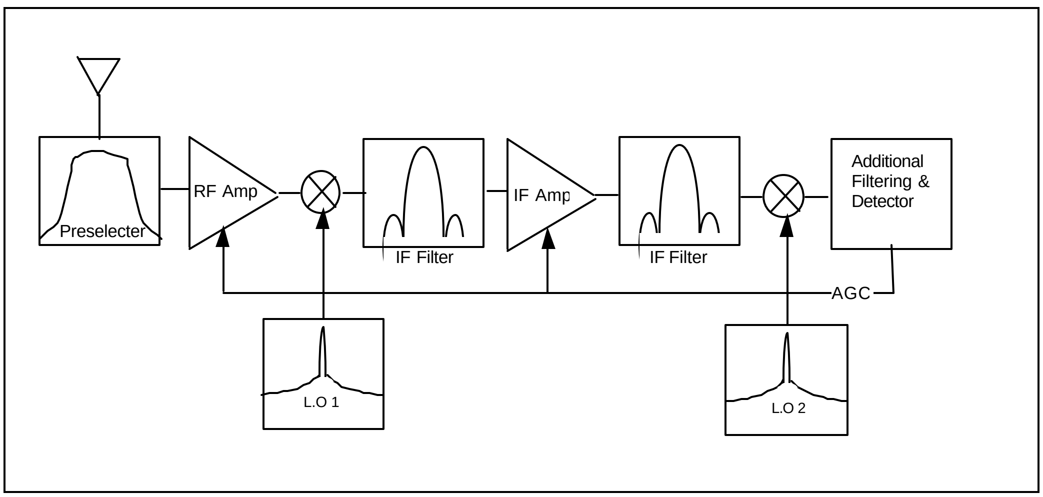


Figure 6 Typical Receiver

5 RECEIVER DESENSITIZATION

Desensitization is the measure of a receiver’s ability to reject signals that are offset from the desired signal’s frequency. Desensitization of a desired signal at the reference sensitivity level due to an adjacent channel signal is defined as Adjacent Channel Rejection (ACR) in the TIA-603 and IS-102CAAA documents. The measurement procedure detailed in the TIA documents for measuring ACR can be used to quantify receiver desensitization at any frequency offset and for higher desired signal levels. [Note that the TIA frequently uses a convention that produces a positive number for specified values. To accomplish this, they use ratios, always placing the largest value in the numerator and then adding an R to the end of the acronym. For example, ACR might be -75 dB, so ACRR would be 75 dB.]

There are several factors that may contribute to a receiver’s desensitization characteristic. The receiver IF selectivity may be inadequate to reject strong signals, typically in excess of -50 dBm, on adjacent channels. Historically this has been a major factor determining the receiver's ability to reject strong signals on adjacent channels. With the availability of small and inexpensive ceramic filters and digital signal processing, it is less of an issue with modern equipment.

Receiver local oscillator sideband noise can heterodyne an undesired signal into the IF pass-band by mixing with a single high level signal, typically in excess of -50 dBm, and usually within 500 kHz of the desired signal. This mechanism is often confused with adjacent channel interference, and it is a contributing factor to the receiver's ability to reject strong signals on adjacent channels.

An additional consideration is the spectrum of the interfering signal. If the interfering signal has a broad spectrum, or a high noise floor, the receiver desensitization measurement will indicate poor desensitization performance even for very well designed receivers. As receivers start utilizing very narrow IF bandwidths (12.5 kHz channel bandwidths or less) the effect due to the modulation components becomes more important. Previously receiver ACRR measurements only required a single 400 Hz tone at 60% of maximum system deviation. This no longer is considered applicable as it severely under estimates the amount of energy that the victim receiver can intercept from an adjacent channel. Currently the TIA recommendations are undergoing changes that will require that the interfering source be modulated so it simulates the energy distribution under actual operating conditions.

Figure 7 shows sensitivity level desensitization performance for a number of generic radios. Also compared in the figure are the desensitization levels due to the off-channel signal source. One of the sources is a high performance signal generator, modulating a 400 Hz tone at 3 kHz deviation. The other source is an iDEN base radio transmitting iDEN Quad-QAM modulation.

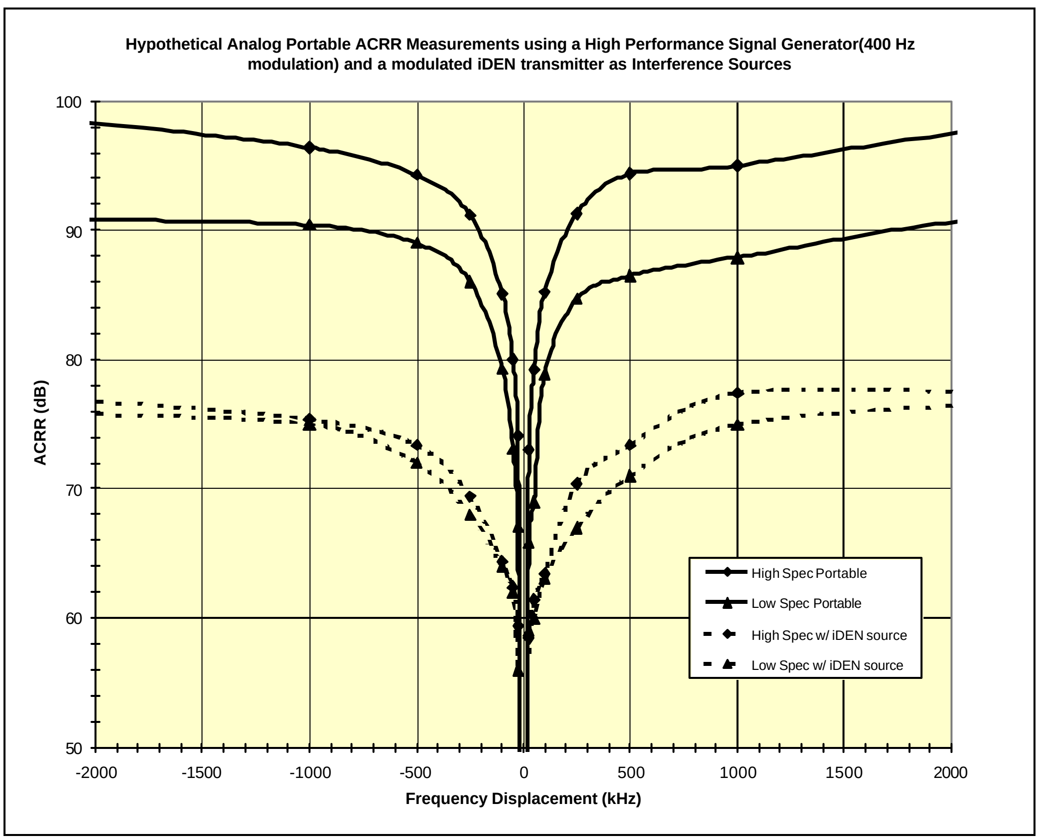


Figure 7 Receiver Desensitization

Figure 7 shows that when a high performance signal generator is used as the interference source, receivers will typically have ≥ 90 dB rejection of signals that are offset ≥ 500 kHz from the desired channel. Receivers usually will have better than ≥ 80 dB rejection for offsets exceeding approximately 50 kHz. When an iDEN base radio is used as the interfering signal source, the ACRR desensitization level is approximately 20 dB less than when the high performance signal generator is used. This occurs due to the noise floor characteristic of linear amplifiers. This indicates that high performance receiver designs may not realize improved desensitization performance because the performance is limited by an unfiltered base radio spectrum that contains high OOBE (noise). There is a penalty for noise limited systems in the same or nearby bands where interference limited systems are deployed.

6 RECEIVER BLOCKING

Excessive desired on-channel signal levels can overload the receiver, usually the result of Automatic Gain Control (AGC) design limitations. The receiver front end can be overloaded by a single high level unwanted signal, not on the desired channel, typically in excess of -25 dBm, or multiple high-level unwanted signals whose total peak instantaneous power exceeds -25 dBm. This is also known as receiver blocking.

Blocking is measured using a desensitization measurement procedure with progressively higher on-channel signal levels. Figure 8 shows the blocking of a hypothetical portable radio, as a function of frequency offset.

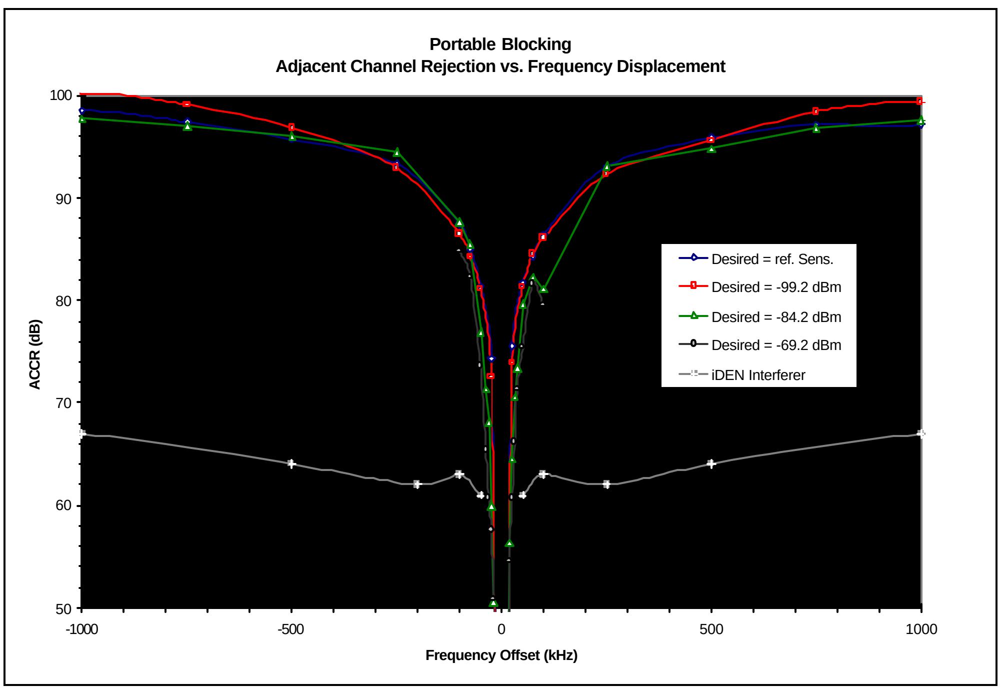


Figure 8 Receiver Blocking

Figure 8 shows that with desired signal levels as high as approximately -70 dBm signal levels, no blocking phenomena occurs. There is a small degradation of the desensitization performance at offsets ≥ 100 kHz for desired signal levels of ≥ -85 dBm.

Figure 8 also demonstrates the desensitization performance at sensitivity level due to an iDEN base radio used as the interfering signal. The desensitization limit imposed by the iDEN OOBE is nearly 20 dB worse than that of the hypothetical radio itself at any desired signal level. From this it can be concluded that ***receiver blocking due to high signal levels is not a significant source of interference, at least where the limiting interference source is from the noise contribution of a base radio generating strong OOB emissions***.

7 RECEIVER INTERMODULATION

Receiver front end (RF Amplifier) non-linearity can create intermodulation products on the desired frequency by mixing two or more high level signals, typically ≥ -50 dBm. Figure 9 shows sensitivity level intermodulation rejection (IMR) for typical receivers, relative to the receiver's reference sensitivity signal level. For practical purposes, IMR is not a function of frequency offset, as the preselector doesn't provide additional rejection of potential Intermodulation combinations across the receiver's desired bandpass. As a result, the IM performance is essentially flat in the desired band. The preselector does provide additional protection from signals outside the pass band. For each additional dB of insertion loss, the IMR products are reduced by the order of the IM product, e.g. 3 dB for 3rd order IM.

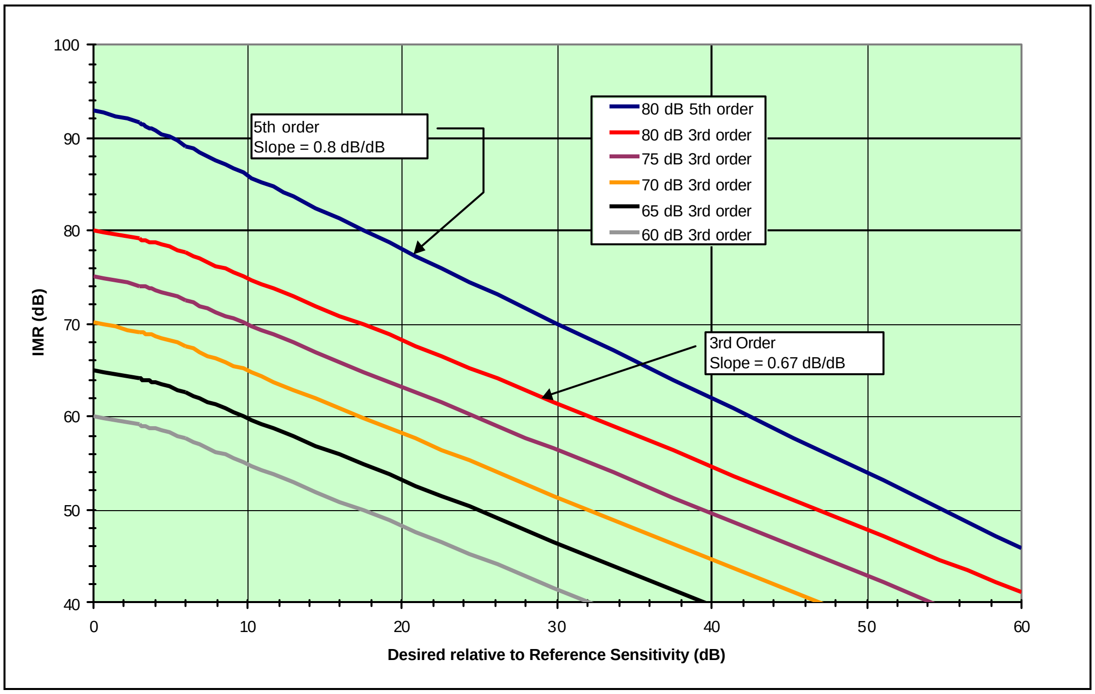


Figure 9 Receiver IM above Reference Sensitivity

While IMR is not a function of frequency offset, it is a function of the level of the desired signal. This is because the signal strength of intermodulation products grows at a rate proportional to the order of the intermodulation product. For example, third order intermodulation products grow 3 dB for every 1 dB increase in signal strengths of the carriers that produce them. Because of this, the IMR is reduced by 2/3 dB for each 1 dB increase in the desired signal level. This effect is shown in Figure 9.

Figure 9 shows that all the products normally follow the 2:3 slope expected for IMR with increasing strength of the desired signal. It is important to note at this point that IMR, as measured using TIA methods, is concerned only with two generator, third order IM processes. Higher order (5th, 7th, 9th, etc., order) processes also exist but are usually of little concern because they usually require much larger interference signal levels than the third order process. Three generator IM processes produce a slightly lower IMR due to the increased power due to the additional signal.

In situations where there is a high concentration of high-powered transmitters with high duty cycles, the higher order IM products can become significant for receivers in close proximity to the site. Figure 9 also shows a 5th order response for an 80 dB (3rd order IMR) receiver. The 5th order IM specification is typically 12 to 15 dB higher than the 3rd order IM specification. Although the 5th order IMR is much higher than the 3rd order IMR, its slope is greater so that 5th order IM can become a problem in situations where there are a large number of carriers. Although not shown, the 1-dB compression point is also very important. The 1-dB compression point exists roughly 10 dB below the IIP^3 and represents where the theoretical slope departs by 1 dB from the linear performance. Signal levels greatly in excess of the 1-dB compression point can cause the amplifier to saturate and eventually burn out.

The use of receiver multicouplers and tower top amplifiers can have a dramatic negative effect on a base station's receiver IMR performance. This is due to the fact that the IIP^3 is constant. The reserve gain of the amplifiers in the configuration raise both the desired signal and the potential IM signals, resulting in a reduction in the system IMR. Figure 10 demonstrates this.

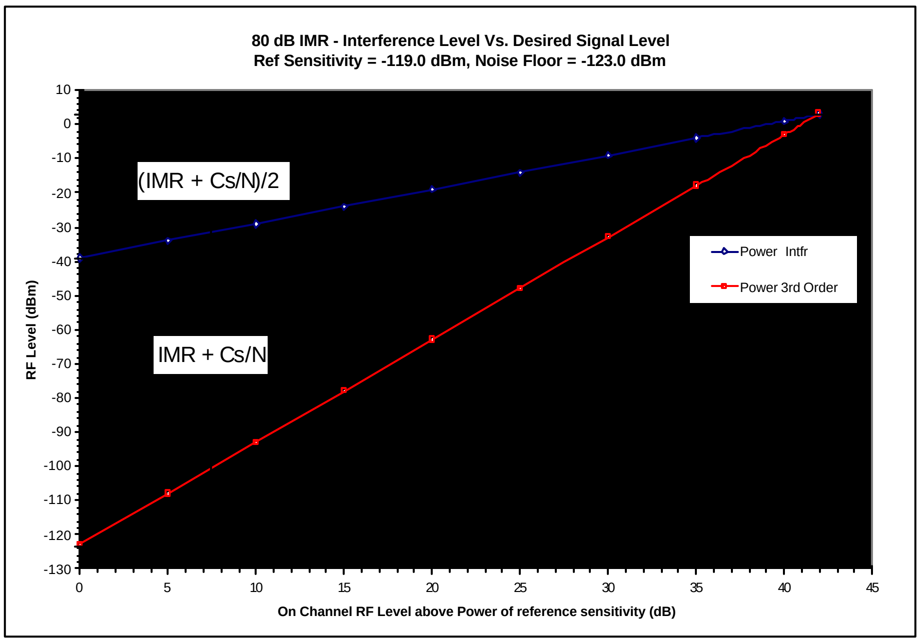


Figure 10 IMR Performance

In Figure 10, the reference sensitivity for 12 dB SINAD is -119 dBm, Cs/N is 4 dB and the IMR is 80 dB. The noise floor calculates to be -123 dBm. The IIP^3 is 1.5*x*(84) or 126 dB above the noise floor (+3 dBm). The individual power level from two equal interferers that produce an IM response on frequency is 42 dB below the IIP^3, -39 dBm.

To review, using the TIA IMR test methodology, consider the previous example. The -119 dBm produces a 4 dB Cs/N that creates the 12 dB SINAD reference sensitivity. The signal is boosted by 3 dB (-116 dBm) and the equal signal level interferers increased until 12 dB SINAD is again reached. This indicates that now a 4 dB Cs/(I+N) has been reached but the desired is now -116 dBm. Thus the composite noise floor is -120 dBm, consisting of -123 dBm from the receiver noise floor and -123 dBm, the equivalent noise from the intermodulating signals. The difference between the original signal (-119 dBm) and the level of the IMR signals (-39 dBm) is the IMR performance of the receiver (80 dB). Note that at higher signal levels, the receiver's own noise floor becomes insignificant and the ratio is merely the difference between the desired and the IMR signals required producing 12 dB SINAD. This explains why the slope in Figure 9 tends to flatten out in the region where the receiver noise floor is significant.

If the desired signal for the example 80 dB IMR receiver is 20 dB above reference sensitivity, -99 dBm, then the difference between the IMR sources and IIP^3 is 102 dB. The level of 2 equal signal IM generating sources 102/3 = 34 dB below the IIP^3. (+3 dBm - 34 dB = -31 dBm). Thus for this example the IMR is now -31 dBm - (-99 dBm) = 68 dB, not 80 dB! In this case the two IMR signals produce an equivalent noise of -102 dBm. The receiver's own noise floor of -123 dBm is insignificant. What is important to note is that even at -99 dBm, the performance is only equivalent to the static reference sensitivity. This phenomenon supports the recommendation for deploying higher IMR receivers when the victim receiver can be close to the source that can produce IMR.

8 RECEIVER SPURIOUS RESPONSES

Receivers can have spurious responses to strong single signals, typically in excess of -50 dBm, which are on frequencies other than the desired receive frequency. Examples include the 1st IF image response, the 2nd IF image response, and any harmonics of the local oscillator mixing with any harmonics of the undesired signal.

Using the typical receiver in Figure 11, if the IF frequency is 11.7 MHz, and the desired signal is 460.0000 MHz, the Local Oscillator must be either 11.7 MHz above or below to cause an 11.7 MHz signal to be generated in the mixer. If the LO is below by 11.7 MHz (448.3 MHz) or above (471.7 MHz) proper operation can occur. With wider preselectors, the image frequency can easily fall within the passband of the preselector. To reduce the possibility of this occurring, the IF frequency should be greater than the preselector's bandwidth. Figure 11 shows how this can occur.

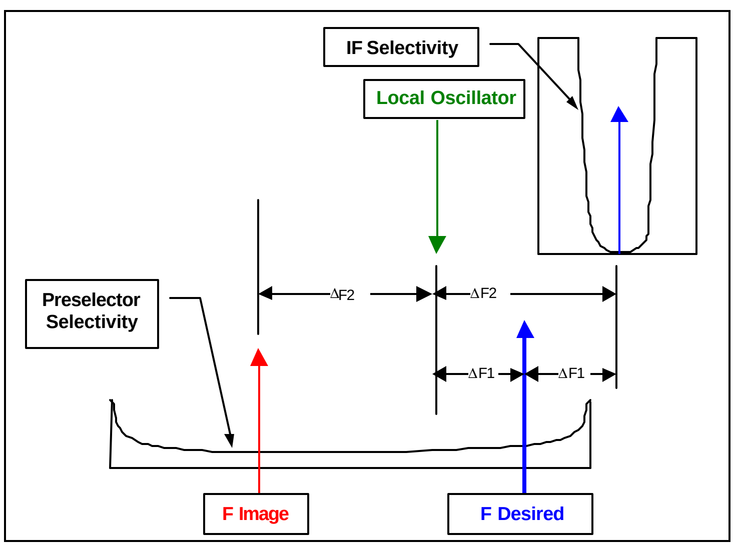


Figure 11 Typical Receiver with a Wide Preselector Passband

The spurious responses of a receiver can cause significant degradation to the desensitization properties of the receiver, on the order of 20 dB in some cases. In most cases, when the interfering signal is due to a base radio with high OOB Emission, the desensitization performance is dominated by that noise floor rather the spurious responses.

9 DETERMINING THE SOURCE OF INTERFERENCE

9.1 TEST EQUIPMENT REQUIRED

1. Spectrum analyzer.
2. Low noise RF amplifier.
3. Step attenuator (pad).
4. Cavity, bandpass filter that has a bandwidth (±3 dB) of at most 300 kHz, an insertion loss of at most 2 dB and that can be tuned to the desired channel.
5. Antenna for the frequency band in question.
6. Subscriber unit that can be connected to a coaxial cable.
7. Motorola Radio Service Software (RSS), or equivalent, loaded on a suitable PC laptop computer to read receive signal strength; if applicable. This capability may not exist for all radios in which case one must listen to the radio's speaker and judge the quieting level.

9.2 EVALUATION PROCEDURE FOR INTERFERENCE TO SUBSCRIBER UNITS

The interference evaluation process begins by visiting the affected location, setting up the subscriber unit and connecting the test equipment as shown in Figure 12 below:

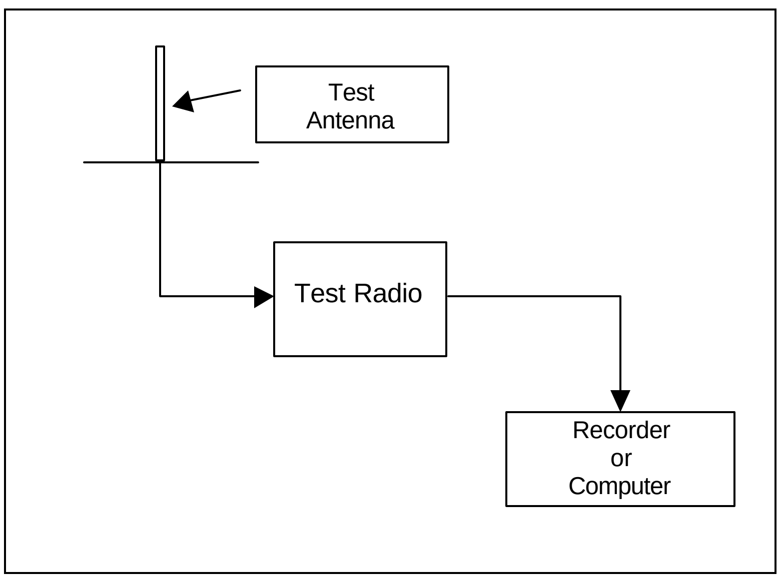


Figure 12 Initial Evaluation

Tune analog units to the appropriate RF channel, and observe the recovered audio quality by recording about two minutes of the audio while slowly driving the test vehicle around in at least a 100-foot circle. The audio should have noticeable degradation compared to the normal reception expected in the general area. After the recording has been made, replay it several times to become familiar with the type of audio degradation that is occurring.

If the subscriber unit uses digital modulation, and the Radio Service Software (RSS) package includes a signal quality metric, it may be more appropriate to record the data from that output on a computer for analysis.

Next, connect the spectrum analyzer to the antenna as shown in Figure 13:

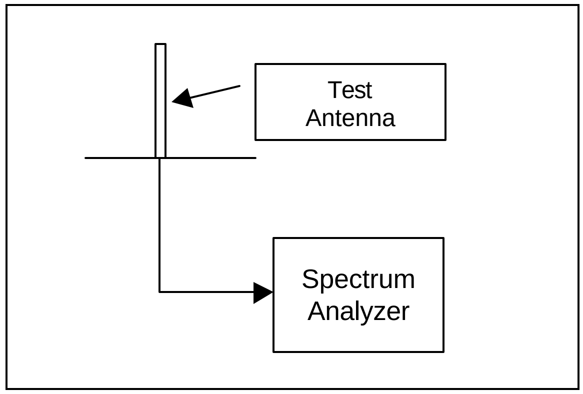


Figure 13 Evaluation with Spectrum Analyzer

Record all signals in the frequency bands that are above (stronger than) -50 dBm. Pay particular attention to those above -40 dBm, as they are the most likely to cause problems, particularly if there are several of them within a few MHz of the desired frequency. A rough guideline is to suspect receiver front-end overload if the total instantaneous peak RF power being delivered to the receiver is in excess of -20 dBm.

In order to correctly measure the power of any RF signal with a spectrum analyzer, it is necessary to use a resolution bandwidth in excess of the maximum spectral distribution of RF energy expected. For analog FM signals, this is typically 10 kHz. For narrowband digital modulation formats, this may be up to 30 kHz, and as much as 1.25 MHz for CDMA transmissions. The reason for this is so that the entire signal will be measured at the same time. The best procedure is to adjust the analyzer frequency span range until the desired signal is centered in the display screen and occupies about 20 percent of the width of the display. Then start at a 1 kHz resolution bandwidth and increase it until there is no further increase in the maximum amplitude shown on the display.

Be aware that multiple RF signals of any modulation format will occasionally add in phase, so that four signals each at a level of -25 dBm will have a total peak instantaneous power that is another 12 dB higher, or -13 dBm.

If there are no strong signals, then the cause is either man-made noise, or co-channel interference from another user on the desired frequency. The difference can be resolved by connecting the equipment as shown in Figure 14:

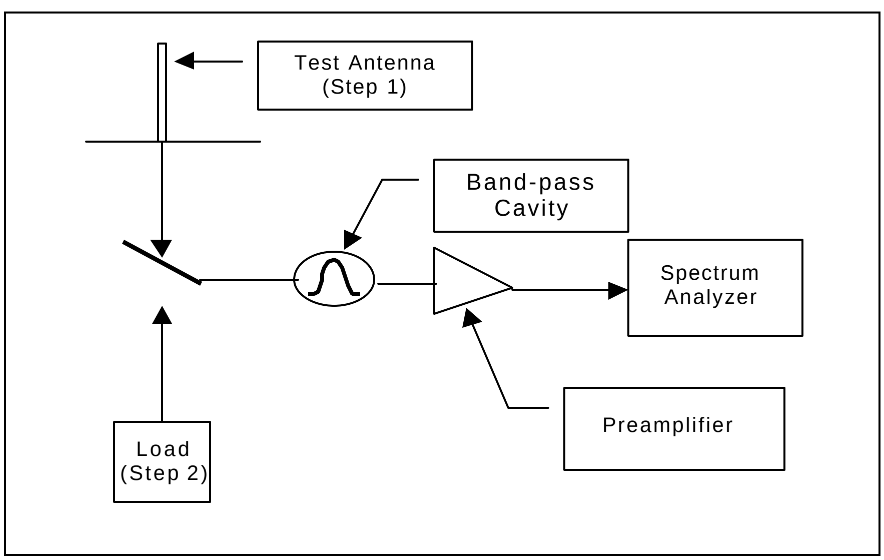


Figure 14 RF Noise Measurement Setup

Using a resolution bandwidth no wider than 3 kHz and a frequency span no greater than 3 times the desired RF channel bandwidth, measure the noise present on the channel, then connect a 50 ohm load in place of the antenna. The noise level should decrease less than 1 dB if there is no noise or interference present. If there is a noticeable reduction, note the amount, then reconnect the antenna, and note the spectral content of the noise. If it is not restricted to the desired channel (Figure 15), then it is most likely either from broadband digital services like CDMA systems or from non-RF sources such as power lines, neon signs, ignitions, and the like. If the noise is shaped to fit the channel (Figure 16), or a single frequency carrier appears in the channel, then co-channel interference is the cause.

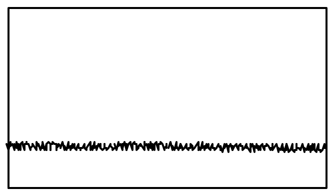


Figure 15 Broadband Noise

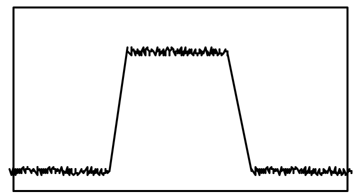


Figure 16 Digital Modulation

If there is only one strong signal present, and it is the desired one, then the cause is one of simple receiver overload. The symptoms are a very high desired signal strength, typically in excess of -30 dBm, with some degree of audio distortion. This is rare, but if it occurs, the only solutions are to move the subscriber unit farther away from the transmitter site, place an attenuator in the receiver's antenna line or reduce the transmit effective radiated power.

If one or more strong signals are present record about two minutes of audio or data on the desired channel using the configuration shown in Figure 17. Listen carefully to the audio recording several times to get familiar with the recovered audio quality.

If the subscriber unit uses digital modulation, compute the average signal strength and signal quality for the entire recording of digital data. Next, add a 5 dB pad in the line between the antenna and the subscriber unit as shown in Figure 17 below:

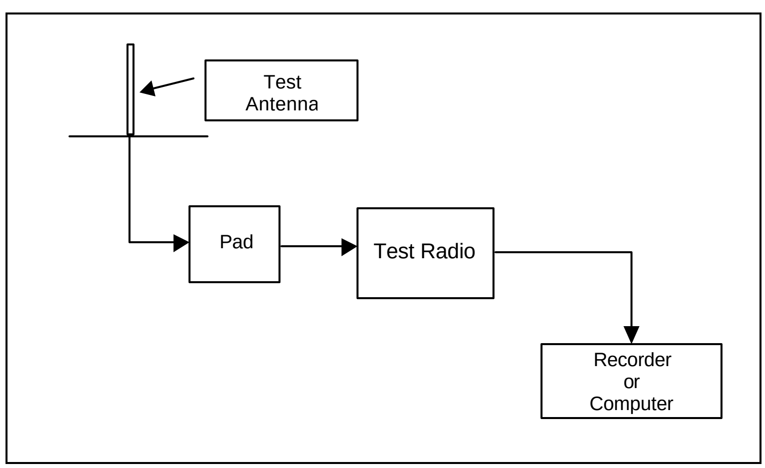


Figure 17 Intermodulation Test

Record another two minutes of audio or data while driving the exact same route as in step 1 and note the differences from the non-attenuated readings. The received signal strength should have been reduced by 5 dB, but if the audio or signal quality ***improved*** noticeably, then the root cause is a high order intermodulation product being generated in the receiver.

Subscriber units using digital modulation will clearly show the reduction in received signal strength while simultaneously indicating the improved signal quality. This type of response usually results from two or more strong signals at the receiver input.

If the received signal strength decreases by 4 dB or less when the 5 dB pad is switched in, the cause is receiver front end overload, resulting from one or more extremely strong signals anywhere in the frequency band. The reason for this is that one of the amplifier stages in the receiver is being driven into saturation by the extremely strong input signals. This effectively reduces the gain of that stage for all signals passing through it. When the strong signals are attenuated by 5 dB, the saturation is reduced, and the effective gain of the amplifier stage increases, so the measured signal strength decreases less than 5 dB. If the audio quality or signal quality remains unchanged when the 5 dB pad is switched in, then the problem is either due to receiver local oscillator noise, or received RF noise from nearby transmitters.

If there are no strong signals closer than 500 kHz away from the desired channel, the cavity filter can resolve whether the receiver is at fault, or the interference is being radiated on frequency from the nearby transmitters. First, connect the external antenna to the analog subscriber unit as shown in Figure 9. Record about two minutes of audio or data on the desired channel. Listen carefully to the audio recording several times to get familiar with the recovered audio quality.

If the subscriber unit uses digital modulation, compute the average signal strength and signal quality for the entire recording of digital data.

Next, connect the antenna through the cavity filter as shown in Figure 18 below:

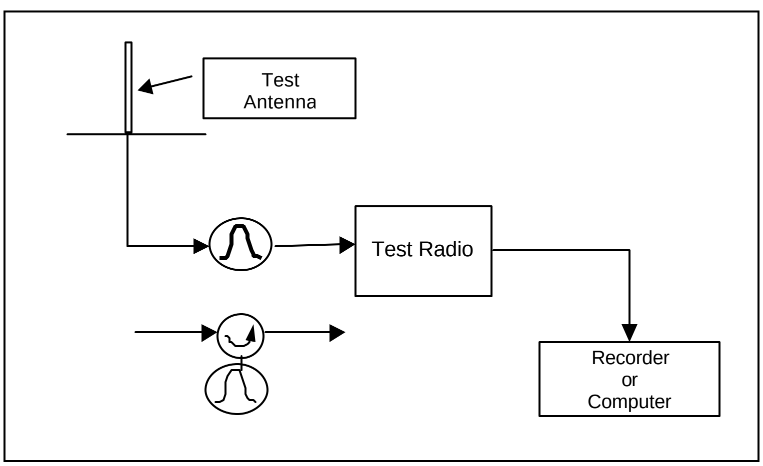


Figure 18 Sideband Noise Determination

Record another two minutes of audio or data on the desired channel. Again listen carefully to the audio recording several times to become familiar with the recovered audio quality. Average the data recorded from digital subscriber units. If the audio quality or average signal quality has improved, the problem is a result of receiver performance limitations.

If it remains about the same, the problem is a result of unwanted RF power being radiated on the desired channel.

It is a special case if any strong signals are less than 300 kHz away from the desired channel. If there are, they are under suspicion right away, especially if they are iDEN signals. A high Q notch filter is needed to perform the above procedure instead of a cavity bandpass filter. This can be achieved by using a bandpass cavity and circulator.

If the above procedures have determined that the problem lies with nearby transmitters, the usual procedures for identifying the exact one or ones apply: If the transmitters are on continuously, shutting them down one at a time can isolate the offender. As this is unpopular with the system operators, a less intrusive method that can be applied if the transmitters are not continuously keyed is to observe the timing of the interference compared to the activity of the nearby transmitters as observed on the spectrum analyzer display.

10 800 MHz BAND EXAMPLE INTERFERENCE SCENARIOS

In most band plans (except Low Band and High Band) there are transition points where the base transmit block of frequencies are adjacent to the base receive block of frequencies. High band and Low band do not follow this due to their earlier development before mobile relay became the dominant type of system deployment. Across this transition there is the potential for base station T to base station R interference in one direction and mobile T to mobile R in the other direction. Within the blocks there is potential for the classic near/far interference scenarios. This can occur as base – mobile interference or mobile – base interference. Recently the frequency of occurrences in the 800 MHz band has become more common, as illustrated in Figure 19.

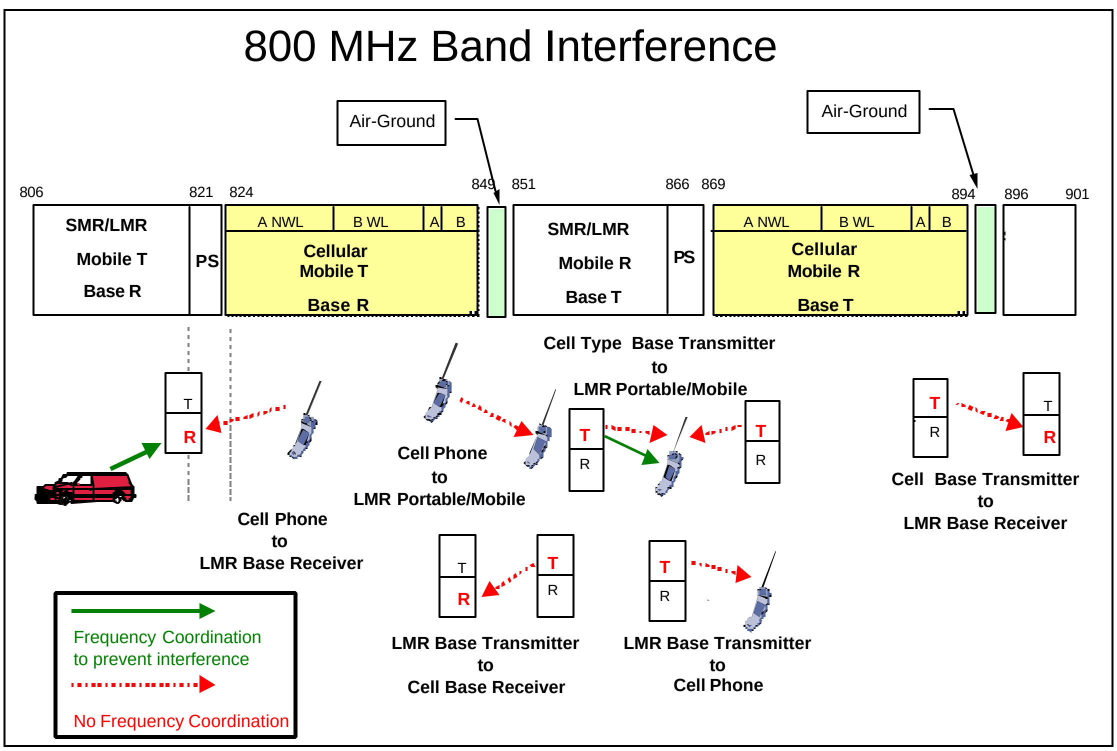


Figure 19 800 MHz Band Interference Scenarios

The following examples (Transmitter to Receiver Cases) will be individually diagrammed, with a table like Figure 20 to show the factors that can create interference, and methods to minimize or prevent that interference.

The logic of the example groupings is that a number describes the type of interference, e.g. Base to Subscriber, but there are different situations because of band breaks or how the systems are deployed.

1 A) LMR[4] Base to LMR Subscriber
B) SMR Base to LMR Subscriber
C) Cellular Carrier Base to Public Safety Subscriber
2 LMR Base to Cellular Phone
3 Cellular Base to 900 MHz Base
4 LMR Base to Cellular Base
5 Cellular Subscriber to LMR Subscriber
6 A) LMR Subscriber to LMR Base
B) Cellular Subscriber to LMR Base

Source of Interference Transmitter Type					
	Cellular Analog	Cellular TDMA	Cellular CDMA	LMR/SMR Analog	LMR/SMR Digital
Transmit Interferor Charteristics					
Combining/ Filtering	High Q Cavity	Hybrid	Multi-CXR Amp	Band Only	
Multiple Transmitters	Yes	No			
Duty Cycle	Intermittent	Continuous			
Power Control	Yes	No			
Isolation From Source	High	Low			
Antenna Type	Omni	Directional			
Victim of Interference Receiver Type					
	Cellular Analog	Cellular TDMA	Cellular CDMA	LMR/SMR Analog	LMR/SMR Digital
Receive Characteristics					
IMR > 75 dB	Yes	No			
Filtering Possible	Yes	No			
Frequency Coordination					
Frequency Coordination	Yes	No			
Type Of Coordination	Co-Channel	Adjacent Channel	Adjacent Band	Guard Band	Reuse Plan
Frequencies Are Closed Spaced	Yes	No			
Sources Are Physically Close (distance)	Yes	No			

Figure 20 Generic Interference Scenario Table

For each example, only the table sections appropriate for that interference scenario will remain legible. Those not appropriate will be darkened. For understanding the table, the rows contain the important information. The columns are not related to each other, other than representing the specific variables being considered in each raw by remaining unshaded.

[4] LMR is Land Mobile Radio

There are two considerations as far as the band is concerned. The cellular band is specifically identified and treated differently than the LMR/SMR band, which includes the exclusive public safety (NPSPAC) portion of the band. For cellular, there are currently three different types of modulations deployed. They include analog, which is referred to as AMPS or NAMPS. AMPS is the original 30 kHz channel bandwidth assignments while NAMPS is a Motorola narrowband version that limits the channel bandwidth to 10 kHz. The Time Division Multiple Access (TDMA) is the 3:1 - 30 kHz channel bandwidth version. Code Division Multiple Access (CDMA) is the 1.23 MegaChip version currently being deployed across markets in the United States. Typically combinations of these modulations can be deployed at any given site. Each cellular carrier selects what they wish to deploy.

In the LMR/SMR band there is currently only analog and some digital, with the digital being principally deployed in the Public Safety band as Project 25 (P-25) systems. However, Nextel has deployed iDEN systems throughout the LMR/SMR band.

Different systems use different transmitter combining techniques. Because LMR systems are narrow band, they typically use Hi-Q cavity combiners, while SMR's frequently uses broadband hybrid combiners to allow frequent frequency changes without requiring site visits.

The Multiple transmitter indication is there to identify where intermodulation products are the easiest to generate.

The duty cycle indicates whether the transmitter(s) are continuous as cellular type deployments require or intermittent as typical of LMR systems use. Note that when a trunking system is involved, the control channel may be continuous while the voice channels are intermittent.

Power Control applies primarily to subscriber units. When power control is available, the subscriber unit limits its output power based on information from the base site. This requires a full duplex path so that the feedback information is constantly updated. For the base station to use power control requires that only a single path be used per base station or that "smart antennas" allow ERP controlled full duplex paths to individual units. This is possible for "interconnect" type calls but isn't possible for dispatch as most of the units are only monitoring the "channel".

The isolation indicated as either High or Low refers to the typical losses involved. There are two different methods used to calculate site isolation. The simplest is to use the port-to-port isolation between the input to one antenna to the output of the other antenna (see the Site Isolation Section 11). The other is to use a propagation model and adjust for the specific antenna gains and propagation losses. The reason for differentiating them is that for the typical scenario being discussed, there is typically between 70 & 75 dB of port-to-port isolation to subscriber units operating in relatively close proximity of the site. Note that the port-to-port isolation eliminates the antenna gains. This makes estimating the effect of OOB emissions much easier. If the OOB emission is -50 dBm, then 70 dB of isolation would produce a -120 dBm interferer at the output of the victim's antenna. However when base-to-base interference is being analyzed, the paths are typically point to point and the antenna gains and minimal free space losses can dramatically reduce the amount of attenuation experienced by the OOB emission. The recent increased usage of "stealth" sites with very short towers has caused a reduction in the amount of site isolation available.

Antenna types are important due to potential directionality.

The victim receiver flag for IM performance is based on the recommendation that 75 dB IMR be a minimal specification. Portable antennas allow some reduction in this requirement as the loss of efficiency acts like an attenuator to potential IM.

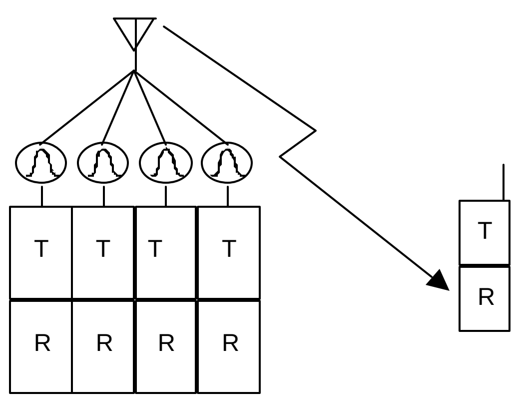
The filtering refers to what can be done at the receiver. Components that are already on frequency cannot be filtered at the victim receiver; they must be filtered at the source. However IM products can be filtered before reaching the active stages of a receiver.

Lastly, the issue of frequency coordination is highlighted. This is an extremely important but not well understood aspect of interference potential. Frequency coordination normally requires that someone (a frequency coordinator) evaluate the use of different candidate frequencies in various defined service areas and then recommends the candidate frequency that doesn't cause interference, or is the best choice from a poor selection. This normally involves evaluating only co-channel usage, but is being expanded to include adjacent channel interference potential. The frequencies are licensed based on the specific site and the ERP being used (referred to as site licensed). SMR's and cellular carriers have special circumstances where they can use any of their inventory of frequencies anywhere in their defined service area, subject to some co-channel reuse limitations where others may be licensed on the same frequencies. As a result, there is no available database of which and where their frequencies are deployed (referred to as area licensed). This allows them the capability of rapidly changing their frequency plan to allow new sites to be deployed thereby adding capacity. A frequency plan covers a wide area and may be coordinated nationwide. A single change can ripple across the entire system, making exceptions more difficult.

The types of coordination are also listed. In some cases a guard band is provided to take the place of frequency coordination. It is implied that when a different band is used, the requirement for frequency coordination is eliminated. Unfortunately, with the wide band and high OOBE of some of the more complex modulations, this assumption is not longer true. The wide band OOBE is radiated into the adjacent or guard band and must be dealt with to minimize interference potential. Cellular type systems utilize frequency reuse plans. This allows a structured starting point for doing internal frequency coordination. The key point is that they are primarily concerned with their own intra-system interference. This type of frequency planning (interference limited) is based on the fact that when the interference gets strong enough, the system will be able to provide an alternative resource that isn't being interfered with.

The other two references under frequency coordination refer to whether or not the frequencies are close (a small frequency offset) or whether units can get into close physical proximity.

10.1 CASE 1A, LMR BASE TO LMR SUBSCRIBER



Source of Interference Transmitter Type					
	Cellular Analog	Cellular TDMA	Cellular CDMA	LMR/SMR Analog	LMR/SMR Digital
Transmit Interferor Charteristics					
Combining/ Filtering	High Q Cavity	Hybrid	Multi-CXR Amp	Band Only	
Multiple Transmitters	Yes	No			
Duty Cycle	Intermittent	Continuous			
Power Control	Yes	No			
Isolation From Source	High	Low			
Antenna Type	Omni	Directional			
Victim of Interference Receiver Type					
	Cellular Analog	Cellular TDMA	Cellular CDMA	LMR/SMR Analog	LMR/SMR Digital
Receive Characteristics					
IMR > 75 dB	Yes	No			
Filtering Possible	Yes	No			
Frequency Coordination					
Frequency Coordination	Yes	No			
Type Of Coordination	Co-Channel	Adjacent Channel	Adjacent Band	Guard Band	Reuse Plan
Frequencies Are Closed Spaced	Yes	No			
Sources Are Physically Close (distance)	Yes	No			

Figure 21 Case 1A LMR Base to LMR Subscriber

This is a very common scenario where a subscriber unit can be very close to a site that generates interference. In this case, the transmitters have Hi-Q cavities to limit the OOBE. The frequency coordination should have eliminated co-channel and adjacent channel interference. If the receiver has an IMR specification of ≥75 dB this scenario would normally be interference free. However, it the undesired IM sources are considerably stronger than the desired signal, the IM "Noise" can prevent the required C/(I+N) from being realized.

However there are some situations where intra site interference can occur for users of that site when they are in close proximity. Figure 21 doesn't show the base receive site configuration. If there is low isolation between the base Transmit and base Receive combiners, then when two subscribers in close proximity to the site transmit a temporary lockup scenario can occur.

Consider the simple two-transmitter/receiver configuration shown in Figure 22. When the subscribers are close to the site, they produce strong signals that can enter the transmitter antenna system. Here the difference in frequencies cross modulate at a loose connector producing the necessary products which are re-radiated to keep the receivers satisfied that they are seeing the correct CTCSS tone or Trunking Connect Tone. When one subscriber de-keys, the cross modulation generates an on frequency interferer that continues to repeat the weak interferer with the other users audio. It is not until the second subscriber de-keys that the lockup will be released.

This can only be resolved by isolating the Transmit and Receive systems, e.g. by vertical antenna separation, and making sure that there are no extraneous locations for this IM to occur. This can also occur externally on the site, such as on rusted tower bolts, etc. For trunking, the use of transmission trunking forces the repeater to also immediately dekey thereby preventing this phenomenon.

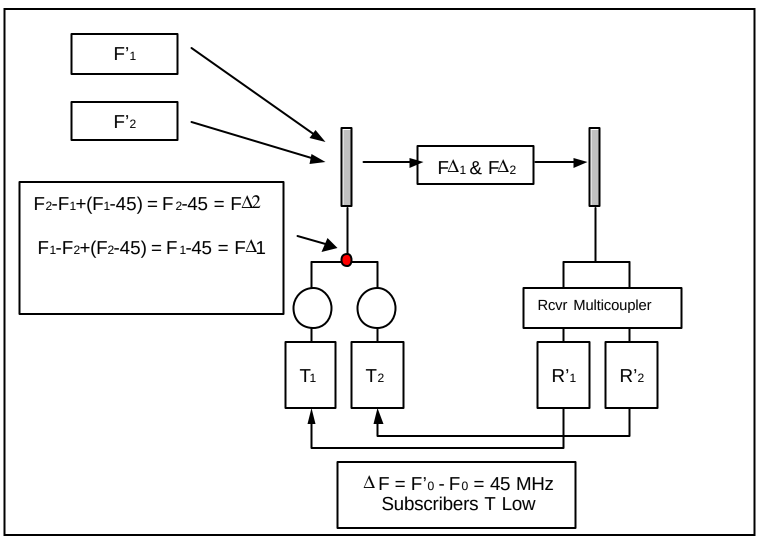
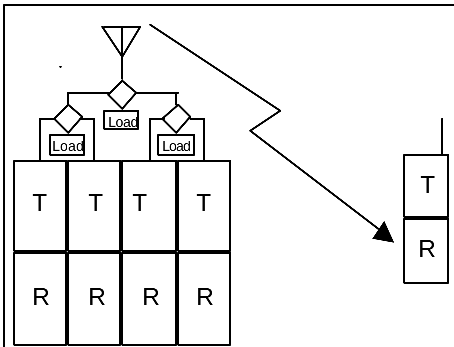


Figure 22 Intermodulation Example

10.2 CASE 1B, IDEN SITE TO LMR SUBSCRIBERS

In Case 1B, the interferer is an iDEN site deploying multiple transmitters as shown in Figure 23. This is a high potential interference scenario due to the fact that the transmitters are hybrid combined and therefore only have limited in-band filtering. The carriers are continuously keyed and subscribers can get in close proximity both in frequency and space with no frequency coordination.

The worst case involves combinations of frequencies that cause on-frequency receiver IM products. This is especially detrimental to receivers with low IMR specifications. If there is sufficient desired signal strength, inserting an attenuator in front of the receiver will reduce both the desired and undesired signals but the IM product of the multiple undesired signals will be suppressed more than the desired signal is attenuated. A building acts much as an attenuator. Building attenuation will reduce the desired by a given amount amount, but it also reduce the IM^3 product by three times the building attenuation, allowing the desired to achieve a usable C/(I+N).



Source of Interference Transmitter Type					
	Cellular Analog	Cellular TDMA	Cellular CDMA	LMR/SMR Analog	LMR/SMR Digital

Transmit Interferor Charteristics					
Combining/ Filtering	High Q Cavity	Hybrid	Multi-CXR Amp	Band Only	
Multiple Transmitters	Yes	No			
Duty Cycle	Intermittent	Continuous			
Power Control	Yes	No			
Isolation From Source	High	Low			
Antenna Type	Omni	Directional			

Victim of Interference Receiver Type					
	Cellular Analog	Cellular TDMA	Cellular CDMA	LMR/SMR Analog	LMR/SMR Digital

Receive Characteristics					
IMR > 75 dB	Yes	No			
Filtering Possible	Yes	No			

Frequency Coordination					
Frequency Coordination	Yes	No			
Type Of Coordination	Co-Channel	Adjacent Channel	Adjacent Band	Guard Band	Reuse Plan
Frequencies Are Closed Spaced	Yes	No			
Sources Are Physically Close (distance)	Yes	No			

Figure 23 Case 1B, SMR iDEN Site to LMR Subscriber

The coordination and reassignment of frequencies deployed at a particular site can eliminate the IMR, allowing the situation to be resolved.

10.3 CASE 1C, CELLULAR CARRIER TO PUBLIC SAFETY SUBSCRIBER

Case 1C is similar to the other Case 1 scenarios except that the interference emanates from transmitters in an adjacent band (Figure 24). The symptoms are similar to the other Case 1 scenarios as this produces coverage holes around the offending site. Due to pressures for minimizing antenna sites, many of the cellular carriers are co-locating. This greatly increases the potential for IMR due to the extremely high number of frequencies involved. The interference potential is increasing as cellular abandons analog for the digital transmitters with higher OOBE and eliminates Hi-Q cavities, deploying multi-carrier transmitters with only band filtering.

This scenario is especially destructive with older portables with 65 dB IMR specifications and preselectors that are designed for International in addition to Domestic distribution. That is because the International band for LMR extends 1 MHz into the Domestic cellular band. This situation is further aggravated if the portables utilize vehicular adapter consoles as this eliminates the portable antenna inefficiency and may even have mobile gain antennas.

Under these circumstances, 5^{th} order IM becomes commonplace. It is not unreasonable for a 20 channel trunked system that has units that operate within ¼ mile of a combined carrier site to have over 1000 IM products distributed randomly over the various frequencies in the 866 - 869 MHz band. For this case, the highest receiver IM performance is mandatory!

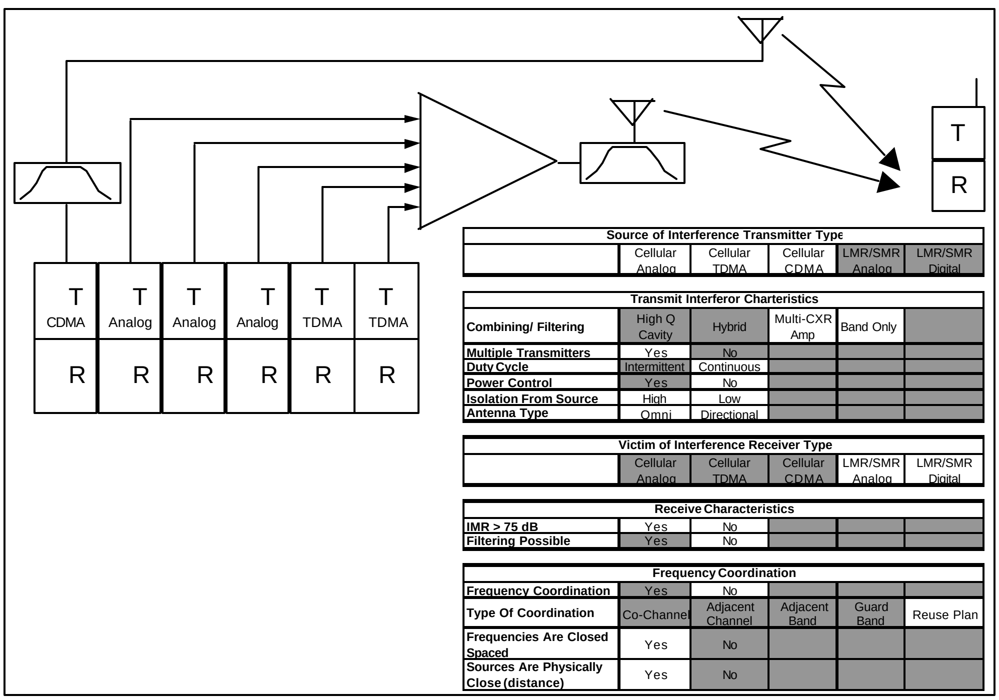


Figure 24 Case 1C, Cellular Carrier Base to Public Safety Subscriber

The Case 1 scenarios all have a similar pattern of interference, wherein the interference potential is maximized where the desired signal is weakest while the interferers are the strongest. This is the classic Near/Far problem (discussed earlier in this document). A typical system wide scenario might look something like Figure 25 with the LMR base in the center. In this case, both Base to Mobile and subscriber-to-subscriber interference is portrayed. Only consider the size of the red zones around interfering sites at this time. The green distribution will be discussed later.

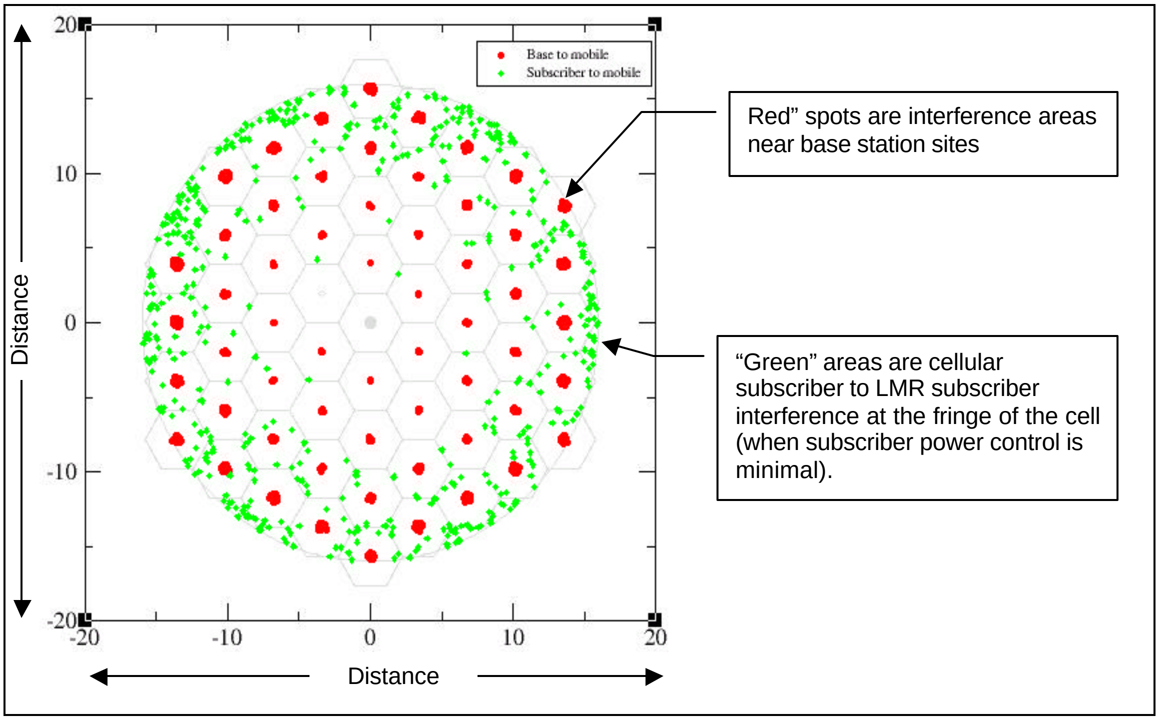
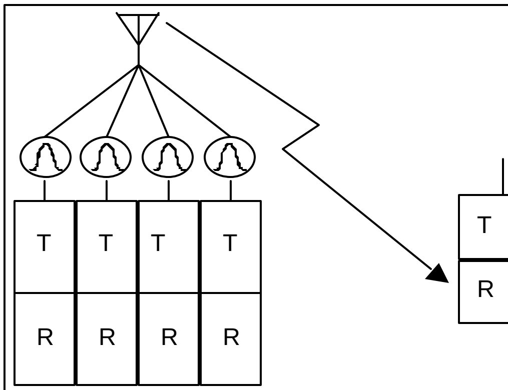


Figure 25 Base to Mobile and Mobile-to-Mobile Interference Pattern

10.4 CASE 2, LMR BASE TO CELLULAR PHONE

Case 2 essentially is the opposite direction from Case 1, where the LMR base station creates coverage holes around its sites for cellular subscribers (Figure 26). Although this case could cause limited interference, it is unlikely due to the fact that the stations are well filtered and the cellular subscribers have alternate sites to be handed over to in case of IMR type interference. Only Public Safety stations operate in the 866 -869 MHz band so their deployment density is quite low compared to the cellular deployment. Also, the LMR transmitters have an internal filter that provides protection above 869 MHz and the HI-Q cavities also limit any OOB emissions.



Source of Interference Transmitter Type					
	Cellular Analog	Cellular TDMA	Cellular CDMA	LMR/SMR Analog	LMR/SMR Digital

Transmit Interferor Charteristics					
Combining/ Filtering	High Q Cavity	Hybrid	Multi-CXR Amp	Band Only	
Multiple Transmitters	Yes	No			
Duty Cycle	Intermittent	Continuous			
Power Control	Yes	No			
Isolation From Source	High	Low			
Antenna Type	Omni	Directional			

Victim of Interference Receiver Type					
	Cellular Analog	Cellular TDMA	Cellular CDMA	LMR/SMR Analog	LMR/SMR Digital

Receive Characteristics					
IMR > 75 dB	Yes	No			
Filtering Possible	Yes	No			

Frequency Coordination					
Frequency Coordination	Yes	No			
Type Of Coordination	Co-Channel	Adjacent Channel	Adjacent Band	Guard Band	Reuse Plan
Frequencies Are Closed Spaced	Yes	No			
Sources Are Physically Close (distance)	Yes	No			

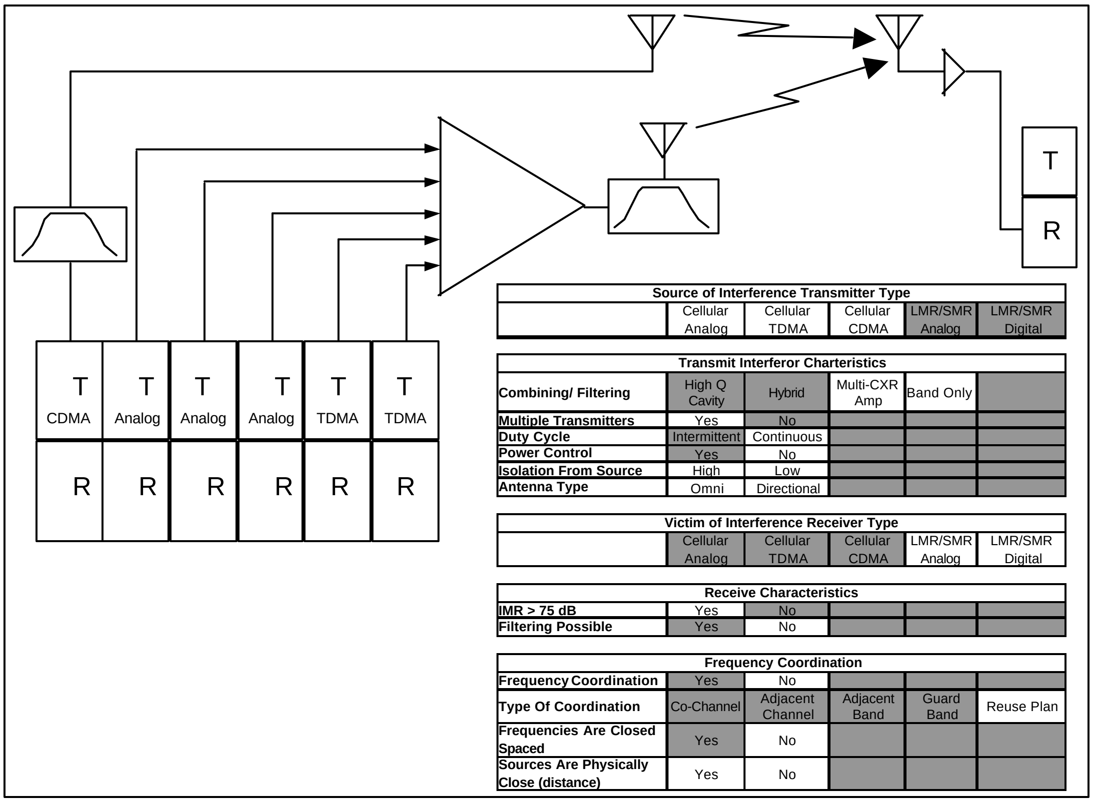
Figure 26 Case 2, LMR Base Station to Cellular Phone

10.5 CASE 3, CELLULAR BASE TO 900 MHZ BASE

Case 3 is the only 900 MHz scenario that will be evaluated (Figure 27). There are several documented cases of this type of interference, primarily caused by the Cellular B carrier. The high OOBE of the various modulations and combinations of modulations along with only band filtering can produce a fairly high noise floor. In this case the noise is amplified by the gain of the transmit antenna and also the receive antenna. Because it is base-to-base interference, the paths often have only free space losses associated with them. At 900 MHz the free space loss between dipoles at 1 mile is 91 dB, but this is reduced by as much as 23 dBd of antenna gains. Thus the isolation is less than 70 dB at one mile. However, sites can be closer than one mile and have even stronger interference potential. When CDMA and mixtures of analog or narrow band analog are present, the potential of IM increases. There is potential IM in the cellular antenna structure that would prevent any filtering at the 900 MHz LMR site from being effective. If CDMA is deployed, then there is also the potential of multiple sources of interference being received. When coupled with high performance TTA's (Tower Top Amplifiers) to compensate for low power 900 MHz products, the probability of interference is increased.

The configuration shown in Figure 27 is very important. Note that the CDMA is on a separate antenna from the narrow band modulations. If they were combined, the resulting IM of the CDMA with the narrow band carriers can create a very strong and wide noise source. Therefore the combining of wide band and narrow band signals in a linear amplifier is not recommended and should be avoided!

Interference from nearby Paging transmitters operating without cavity filtering is also a frequent source of reduced coverage for 900 MHz base receivers. Excess reserve gain in the TTAs on sites with high ambient noise levels will also reduce coverage.



Source of Interference Transmitter Type					
	Cellular Analog	Cellular TDMA	Cellular CDMA	LMR/SMR Analog	LMR/SMR Digital

Transmit Interferor Charteristics					
Combining/ Filtering	High Q Cavity	Hybrid	Multi-CXR Amp	Band Only	
Multiple Transmitters	Yes	No			
Duty Cycle	Intermittent	Continuous			
Power Control	Yes	No			
Isolation From Source	High	Low			
Antenna Type	Omni	Directional			

Victim of Interference Receiver Type					
	Cellular Analog	Cellular TDMA	Cellular CDMA	LMR/SMR Analog	LMR/SMR Digital

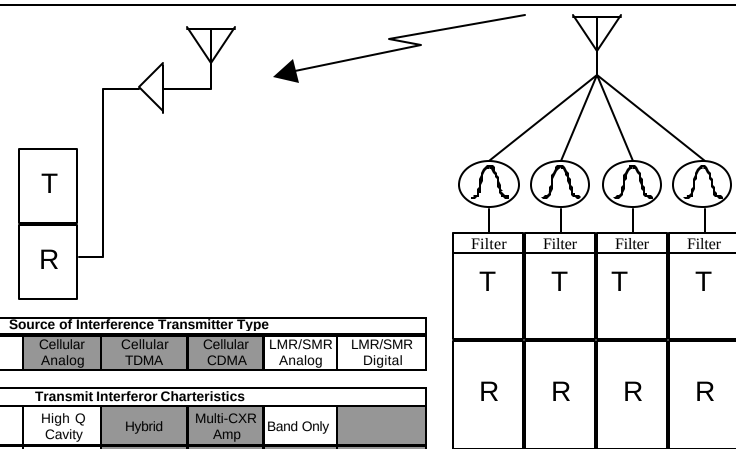
Receive Characteristics					
IMR > 75 dB	Yes	No			
Filtering Possible	Yes	No			

Frequency Coordination					
Frequency Coordination	Yes	No			
Type Of Coordination	Co-Channel	Adjacent Channel	Adjacent Band	Guard Band	Reuse Plan
Frequencies Are Closed Spaced	Yes	No			
Sources Are Physically Close (distance)	Yes	No			

Figure 27 Case 3, Cellular Transmitters to 900 MHz Base Receivers

10.6 CASE 4, LMR BASE TO CELLULAR BASE

Case 4 has LMR base stations causing potential interference to Cellular Base station receivers (Figure 28). There is little likelihood of this because there is a 2 MHz guard band between the LMR band and the cellular band. Motorola LMR base stations are heavily filtered and provide over 50 dB of suppression at the high end of the base receive band as shown in Figure 29. This coupled with Hi-Q cavity filters should suppress OOB emissions adequately to prevent cellular base stations from being interfered with. Even if they were interfered with, the density of LMR base stations is quite low compared to cellular base stations. The cellular system's ability to hand over subscribers to other resources make this type of interference even less likely.



Source of Interference Transmitter Type					
	Cellular Analog	Cellular TDMA	Cellular CDMA	LMR/SMR Analog	LMR/SMR Digital
Transmit Interferor Charteristics					
Combining/ Filtering	High Q Cavity	Hybrid	Multi-CXR Amp	Band Only	
Multiple Transmitters	Yes	No			
Duty Cycle	Intermittent	Continuous			
Power Control	Yes	No			
Isolation From Source	High	Low			
Antenna Type	Omni	Directional			
Victim of Interference Receiver Type					
	Cellular Analog	Cellular TDMA	Cellular CDMA	LMR/SMR Analog	LMR/SMR Digital
Receive Characteristics					
IMR > 75 dB	Yes	No			
Filtering Possible	Yes	No			
Frequency Coordination					
Frequency Coordination	Yes	No			
Type Of Coordination	Co-Channel	Adjacent Channel	Adjacent Band	Guard Band	Reuse Plan
Frequencies Are Closed Spaced	Yes	No			
Sources Are Physically Close (distance)	Yes	No			

Figure 28 Case 4, LMR Base to Cellular Base

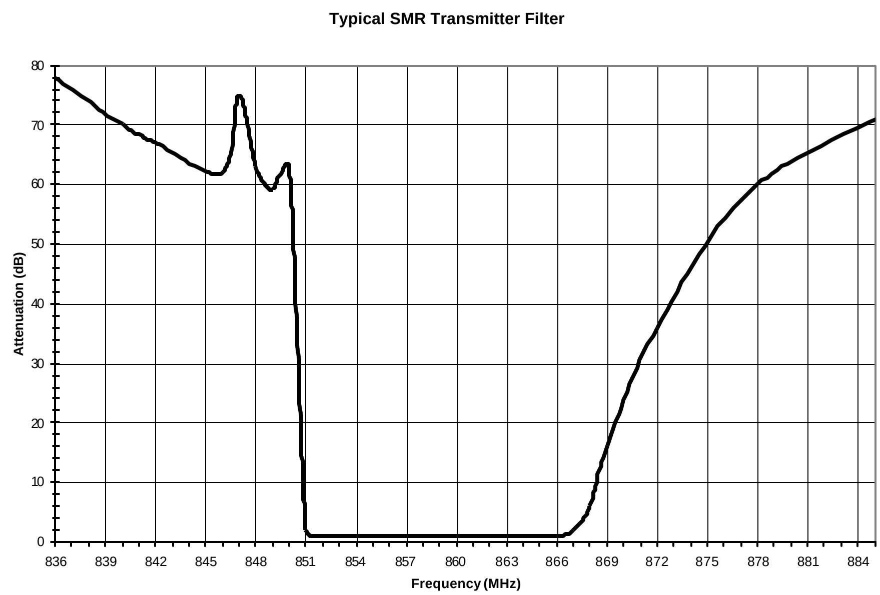
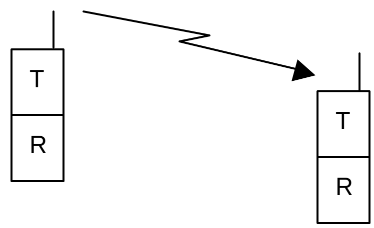


Figure 29 Typical Motorola iDEN Base Station Internal Bandpass Filter

10.7 CASE 5, CELLULAR SUBSCRIBER TO LMR SUBSCRIBER

Case 5 is where Cellular Subscriber units can interfere with LMR subscriber units (Figure 30). There are several mechanisms that need to be discussed. First there is the direct subscriber-to-subscriber interference. Here the high allowable OOBE of cellular subscriber units can cause localized interference around those units when the cellular units are far from their sites (power control doesn't limit the power output) and the LMR unit is far from its desired signal. Figure 21 shows this as the light green blotches associated with the fringe of the cell sites.

The use of CDMA subscriber units is more worrisome as multiple units can be transmitting simultaneously on the same wideband frequency. Often a large population of cellular users coincident with a major public safety event can occur. Now the large population of subscribers in close proximity both in frequency and distance can increase the potential for interference. In addition, if the public safety event is close to a cellular site and a large population of cellular subscribers occurs, then there is also the opportunity for receiver IM to occur. In a well documented case in Canada, intermittent interference occurred to the direct mode of fire fighter portables.



Interference Scenario					
Source on Interference					
	Cellular			LMR / SMR	
Interference Source Transmitter Type	Analog	TDMA	CDMA	Analog	Digital
Combining / Filtering	Hi Q Cavity	Hybrid	Multi-CXR Amp	Band Only	
Multiple Transmitters	YES*	NO			
Duty Cycle	Intermittent	Continuous			
Power Control	YES	NO			
Isolation from Source	High	Low			
Antenna Type	Omni	Directional			
Victim					
IMR > 75 dB	YES	NO			
Filtering Possible	YES	NO			
Frequency Coordination					
Frequency Coordination	YES	NO			
Type of Coordination	Co-Chan	Adj-Chan	Adj-Band	Guard Band	Reuse Plan
Frequencies are close spaced	YES	NO			
Sources are physically close (distance)	YES	NO			

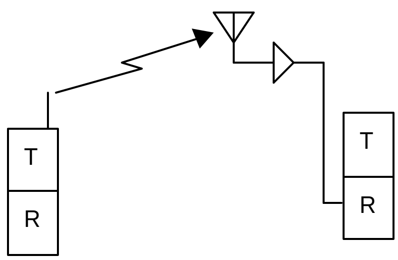
Figure 30 Case 5, Cellular Subscriber to LMR Subscriber

10.8 CASE 6, SUBSCRIBER TO LMR BASE

Case 6 involves interference from subscriber units to LMR base receivers (Figures 31 & 32). Again this is a classic Near/Far scenario. Receiver voting in the LMR system is the best defense for this type of interference, recognizing that for analog systems strong interference can be misinterpreted as a desired signal. Proper use of sub-audible codes can mitigate the undesired voting potential with the voting offering the decreased likelihood that multiple interfering scenarios occur simultaneously.

Case 6A involves the in-band LMR case. In many systems, TTA's are used to increase sensitivity for fringe talk-in. However, this also increases the susceptibility to interference. A special case is where the LMR subscriber is a control station. This can produce the example of system cross talk and temporary lockup previously described. The area of maximum impact is a reduction in the base talk-in coverage.

Case 6B is the cellular case. Here subscriber units have power control so they would have minimal impact if the cellular site and LMR sites are co-located.



Interference Scenario					
Source on Interference					
	Cellular			LMR / SMR	
Interference Source Transmitter Type	Analog	TDMA	CDMA	Analog	Digital
Combining / Filtering	Hi Q Cavity	Hybrid	Multi-CXR Amp	Band Only	
Multiple Transmitters	YES*	NO			
Duty Cycle	Intermittent	Continuous			
Power Control	YES	NO			
Isolation from Source	High	Low			
Antenna Type	Omni	Directional			
Victim					
IMR > 75 dB	YES	NO			
Filtering Possible	YES	NO			
Frequency Coordination					
Frequency Coordination	YES	NO			
Type of Coordination	Co-Chan	Adj-Chan	Adj-Band	Guard Band	Reuse Plan
Frequencies are close spaced	YES	NO			
Sources are physically close (distance)	YES	NO			

Figure 31 Case 6A, LMR Subscriber to LMR Base

Interference Scenario					
Source on Interference					
Interference Source Transmitter Type	Cellular			LMR / SMR	
	Analog	TDMA	CDMA	Analog	Digital
Combining / Filtering	Hi Q Cavity	Hybrid	Multi-CXR Amp	Band Only	
Multiple Transmitters	YES*	NO			
Duty Cycle	Intermittent	Continuous			
Power Control	YES	NO			
Isolation from Source	High	Low			
Antenna Type	Omni	Directional			
Victim					
IMR > 75 dB	YES	NO			
Filtering Possible	YES	NO			
Frequency Coordination					
Frequency Coordination	YES	NO			
Type of Coordination	Co-Chan	Adj-Chan	Adj-Band	Guard Band	Reuse Plan
Frequencies are close spaced	YES	NO			
Sources are physically close (distance)	YES	NO			

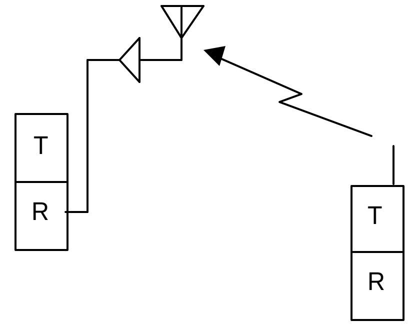


Figure 32 Case 6B, Cellular Subscriber to LMR Base

The use of macro diversity (voting) is the best tool for the prevention of this type of interference.

Figure 33 depicts a special case where the cellular system and LMR system are co-located. This essentially minimizes the size of the reduced coverage. If a LMR site were at the junction of three cells, then the potential for multiple interferers transmitting at maximum output power would produce a much worse case. Fixed cellular units, similar to LMR control stations are also a potential problem. In this case the small red diamonds represent the cellular type deployment of sites.

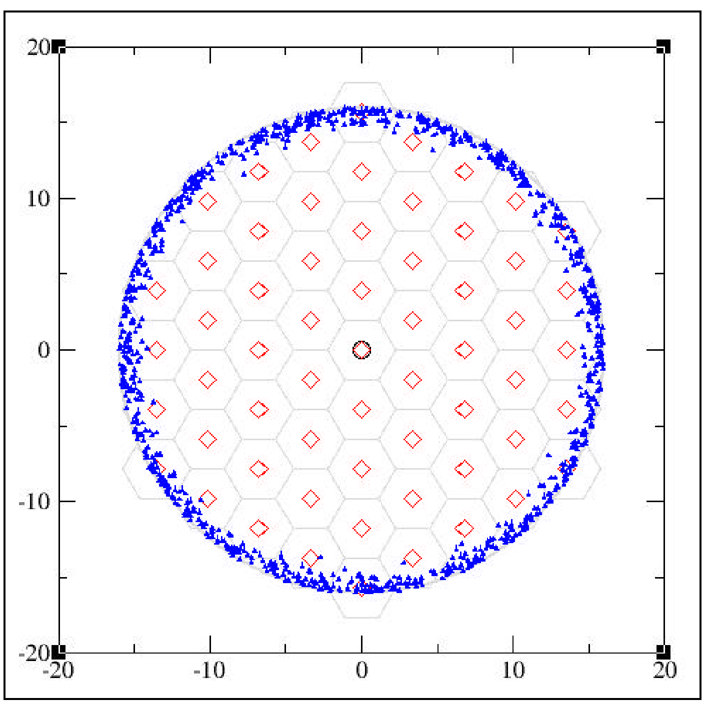


Figure 33 Co-Located Cellular System and LMR System

11 SITE ISOLATION

As described earlier, there are two ways of predicting the losses between a base station and a subscriber unit at close distances. The antenna patterns aren't completely formed and in many cases there are little to no obstructions to increase the losses.

Numerous investigations have been made. Dr. Garry Hess reported on this in his books, and numerous measurements have been made while investigating interference cases.

Figures 35, 36 and 37 show the results of measurements made in the Motorola Schaumburg parking lot many years ago. Note that except for the very low antenna case, all the port-to-port isolation measurements produced ≥65 dB of path loss [isolation] for omni directional antennas. The near/far field transition occurs at ~36 feet. This particular pattern is very important as lower antenna heights are being deployed and this lowers the anticipated site isolation by eliminating the additional isolation produced by the transmit antenna pattern.

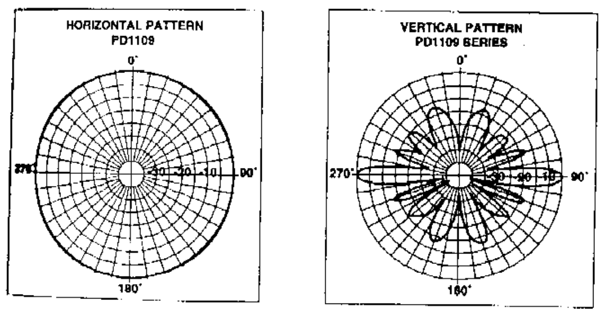


Figure 34 PD 1109 Antenna Pattern.

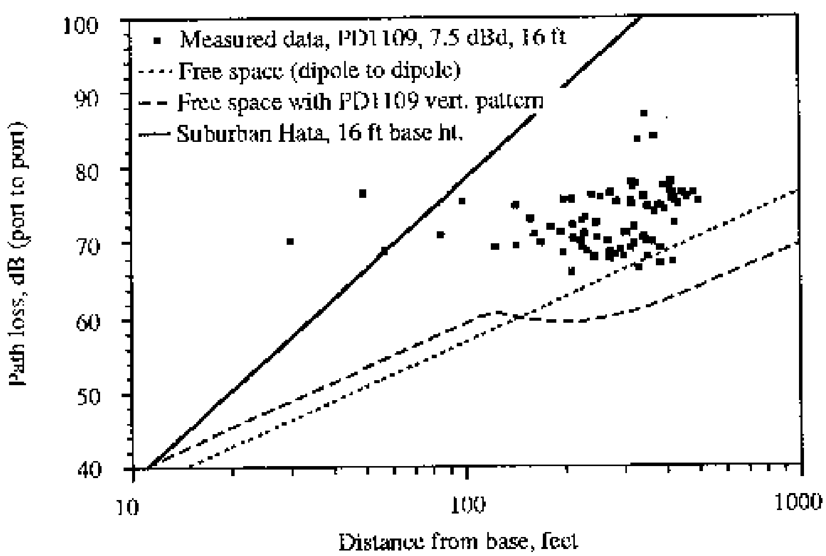


Figure 35 PD1109 @ 16 Ft Above Receive Antenna

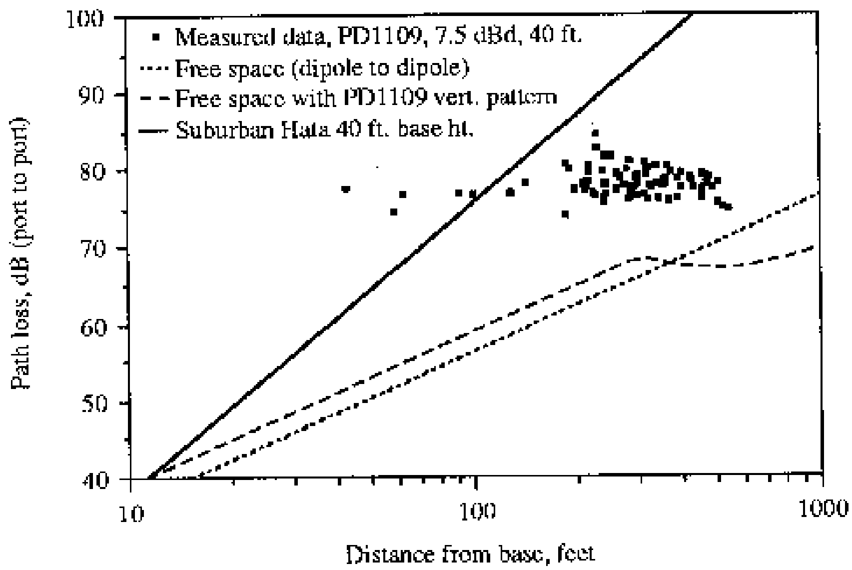


Figure 36 PD1109 @ 40 Ft Above Receive Antenna

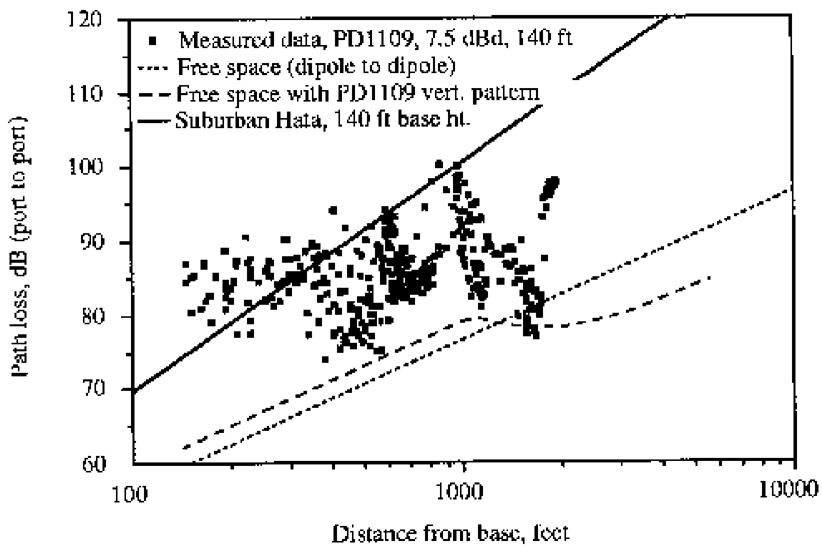


Figure 37 PD1109 @ 140 Ft Above Receive Antenna

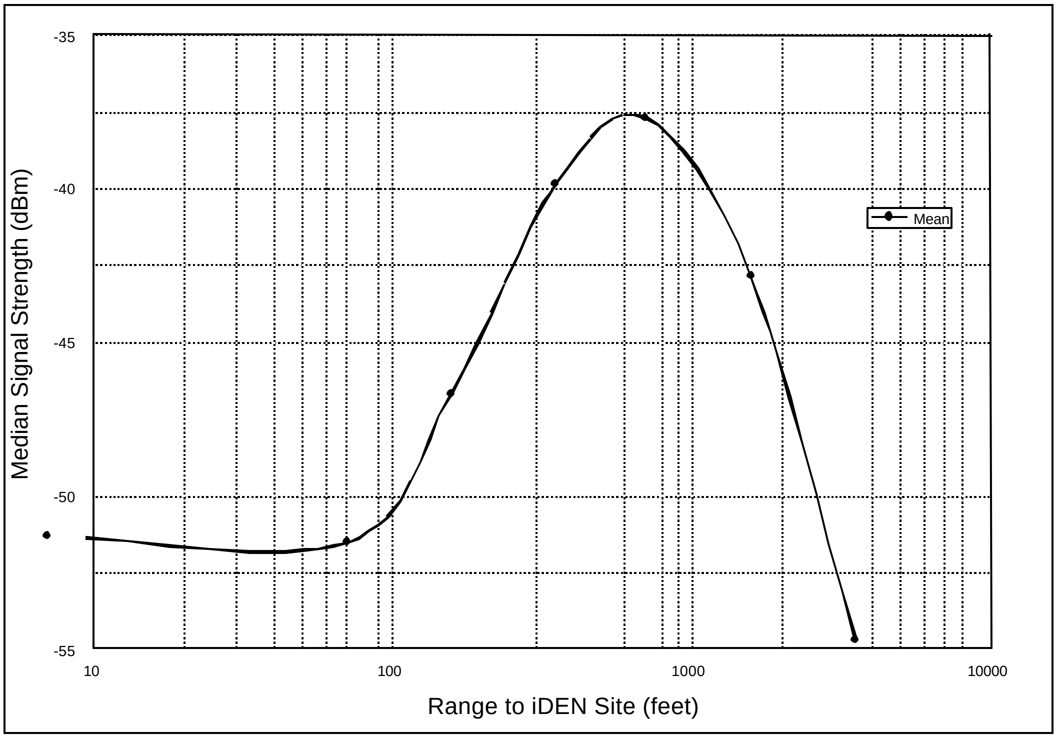


Figure 38   Median Signal Strength Model for Measured iDEN Sites

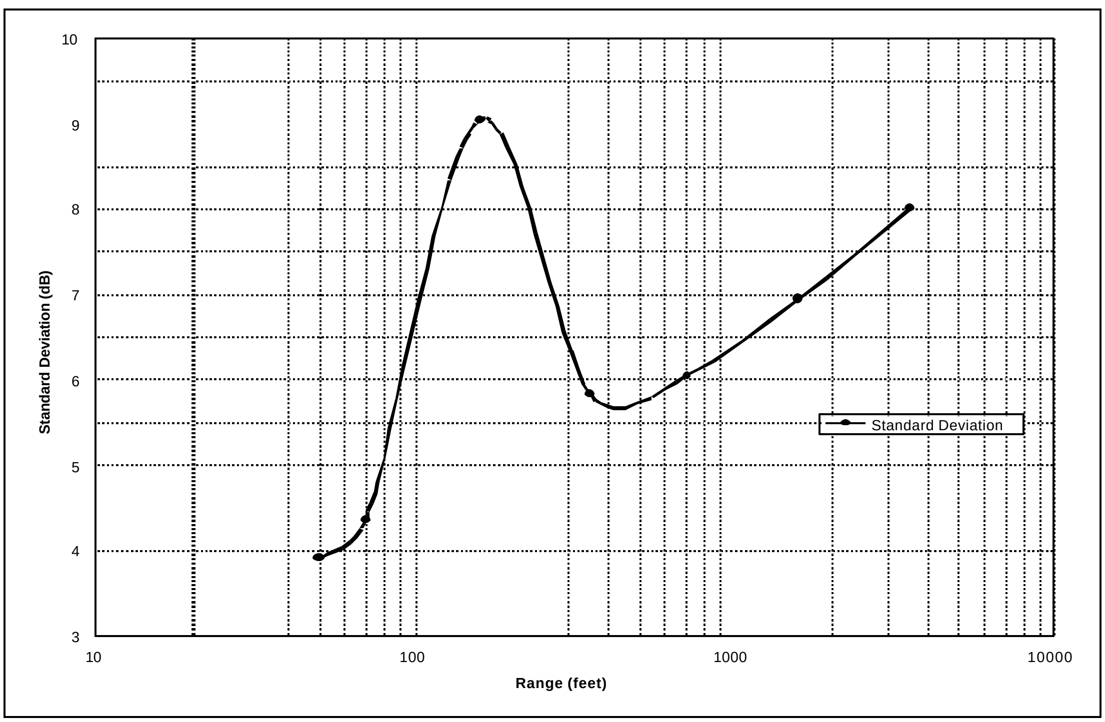


Figure 39 Standard Deviation of Received Power from iDEN Sites vs. Range (measured)

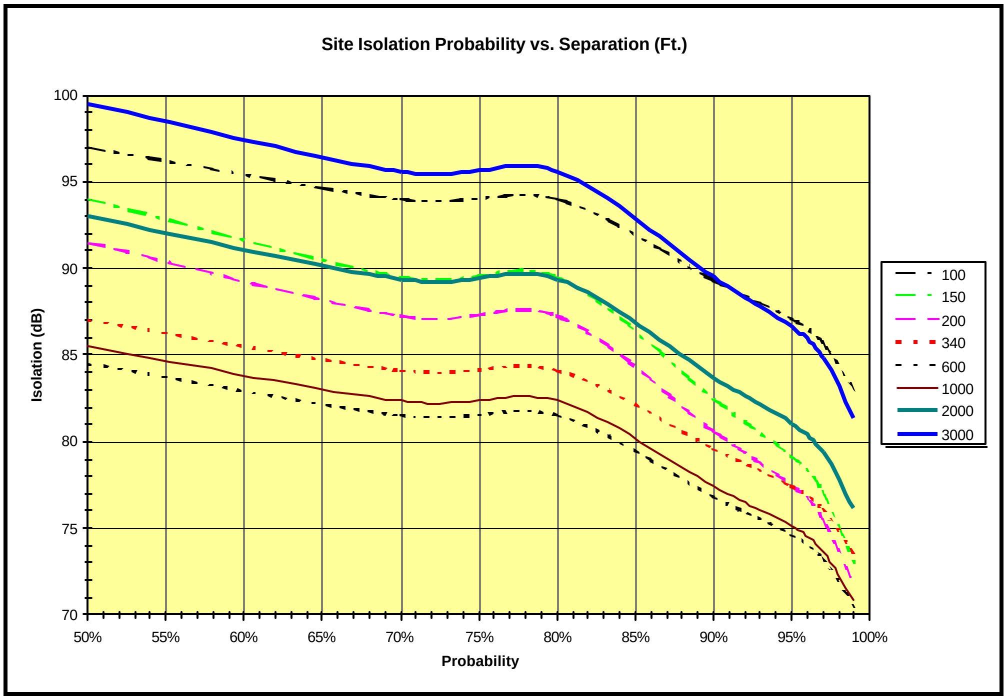


Figure 40 Calculated Probability of Site Isolation

Compare this to a simple spreadsheet model. This allows a coarse look at the port-to-port isolation (Figure 41). The scenario consists of a tower 100 feet tall, a 105° sectored antenna with 11.8 dBd gain, and an arbitrary 10 dB of clutter loss. The primary point to note is that the isolation is greater than 75 dB and that the general shape of the graph is quite similar to the standard deviation of field measurements (Figure 39). The standard deviation is highest in the region closest to the base of the tower, as this is where nulling of the antenna sidelobes occurs. Since there were many different types of antennas involved in the data, the largest variations occur in this region.

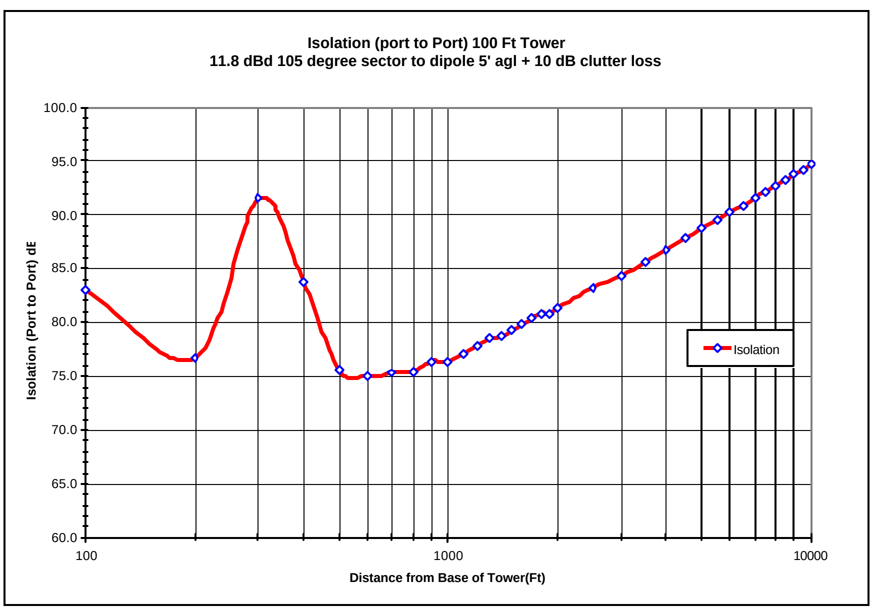


Figure 41 Port-to-Port Isolation

12 RESOLVING INTERFERENCE

The following sections describe actions that can be taken to minimize Radio Frequency Interference (RFI) between systems operating at 800 MHz within the same geographical location. These guidelines are general in nature and these same techniques and philosophies can be applied to most any systems experiencing RFI. Thorough testing will determine actual causes (in some cases, multiple causes) and sources of interference that the system is experiencing. Therefore, thorough testing should precede and follow the application of any solutions proposed below to determine the appropriate actions required and the effectiveness of the deployed solution.

12.1 RECOMMENDED RESOLUTION PROCESS:

1. Identify performance issue as RF Interference.
2. Identify potential source(s) of the interference.
3. Contact other system operators to cooperatively identify the interference issue. The correct and accurate assessment of the interference mechanism is critical to developing an action plan that will rectify the situation.
4. FCC rules stipulate that the two system licensees must work cooperatively to resolve any reports of interference.
5. Implement required changes.
6. Monitor performance.
7. Maintain communications with other operators as the site/system evolves.

12.2 METHODS TO REDUCE INTERFERENCE OF SPECIFIC TYPES

12.2.1 POSSIBLE ACTIONS TO REDUCE THE EFFECTS OF TRANSMITTER SIDEBAND NOISE:

- Change frequencies to increase frequency spacing between the channels.
- Lower transmitter power as much as possible. This can reduce coverage and move traffic to surrounding sites if there is sufficient coverage overlap. The resulting reduction in carried load may allow a reduction in the number of transmitters that will also reduce the noise floor rise due to transmitter sideband noise.
- Increasing the center of radiation on the undesired transmit antennas > 80’ AGL will increase the local path loss to the affected units and reduce the noise floor rise due to antenna discrimination.
- Increase desired signal level. This may be accomplished by increasing desired ERP (more power or higher gain antennas) or adding desired sites.
- Co-locating sites will maximize the desired signal strength where the undesired energy is strongest.
- Change antennas in an attempt to reduce the undesired signal level in the immediate area of a site. This may be a change of pattern, the removal of down-tilt, less energy in lower lobes or higher gain (narrower vertical beamwidth).
- Use cavity combiners instead of hybrid combiners. Use only when the recommended tests have demonstrated that cavities will help. Note that some auto-tune cavity combiners may not work properly with iDEN’s Quad-QAM modulation.
- Escalate the construction of new sites in surrounding areas to allow further reduction in ERP.
- Swap frequencies or segregate spectrum. These alternatives would require FCC approval.

12.2.2 POSSIBLE ACTIONS TO REDUCE THE EFFECTS OF PORTABLE RECEIVER IM

- Increase desired signal strength by adding sites or changing antennas.
- Avoid using portables with an IM specification < 75 dB. Portables with higher IM specifications are much more immune to IM interference.
- Design systems for in-building coverage. This will present higher desired signal levels "on-the-street", overriding IM interference where it is more likely to occur - on the street near low sites. (The undesired signal strengths are typically attenuated inside buildings and the strength of the IM mix is typically insufficient to interfere with the desired signal.) This may allow portables with lower IM specifications (i.e. IM $\leq$ 70 dB) to be utilized.
- Determine the frequencies being used by each operator. Attempt to coordinate to prevent creating third and fifth order Intermodulation (IM) products. Change the receive and transmit frequency plan so that IM products do not fall on receive channels.
- Reduce the ERP of the undesired transmit channels as much as possible. A 1 dB reduction in ERP will reduce 3rd order products by 3 dB and 5th order products by 5dB. This reduction in ERP is likely to reduce the number of transmitters that can contribute to mixes as the traffic is offloaded to surrounding sites.
- Change portable antennas. Reduce portable antenna gain if there is sufficient desired signal. Each 1 dB reduction in gain will reduce 3rd order products in the receiver front-end by 3 dB and 5th order products by 5 dB.
- Use voting receivers to minimize the impact of portable interference to base receivers.
- Sweep the transmit antenna system or check the tuning on the combiners to reduce transmitter generated IM.
- Swap frequencies or segregate spectrum. These alternatives would require FCC approval. Consolidated spectrum would tend to create tightly clumped IM products. Existing interlaced frequency allocations spread out the IM products across much of the band.

12.2.3 POSSIBLE ACTIONS TO REDUCE THE POSSIBILITY OF INTERFERENCE IN THE FUTURE

- Maintain constant communication between license holders to coordinate frequency deployments and system expansion plans and actions.
- Co-locate sites whenever possible.
- Swap frequencies to remove interlaced frequency assignments - requires FCC approval.
- Segregate frequencies into sub-bands and either minimize use of frequencies at sub-band edge or establish guard bands between sub-bands.

12.3 INTERFERENCE REDUCTION METHODS

The following section describes various methods for minimizing or eliminating interference. Most often, the interference is not totally eliminated, it is just reduced to levels that where acceptable communications can be maintained.

Multiple methods must often be employed. One method may reduce a certain kind of interference and then a different type of interference may then be revealed. Only thorough testing will completely characterize the interference types that are occurring in any given situation. The “best” solution for any given case will depend on many factors including the individual circumstances of the location. What worked in one case may not work as well in another case. For example, a change of frequencies in one case may not be possible in another case.

These solutions are offered as a menu of possible choices. The optimal applications of the various solutions will be determined by the details of each and every situation.

12.3.1 CHANGE FREQUENCY PAIRS

Changing frequencies is a relatively easy way to avoid both Side Band Noise (SBN) and Intermodulation (IM) interference if this flexibility exists in any given case. Changing frequencies in a frequency reuse system has multiple effects that ripple across many sites if not the entire service area.

Increase the frequency spacing between channels to address sideband noise issues. Moving one or more close spaced frequencies can reduce the amount of sideband noise that can fall on nearby channels. Frequency spacings of 150 KHz or greater permits the use of filtering on the transmitter. Greater frequency spacings generally offer increased protection.

Changing transmit frequencies involved in an IM product can be used to move the mix to a channel that is not used in the area or to a frequency that is more immune to the IM product. Receiver frequencies can be moved from channels where IM mixes occur.

In some cases an exchange of frequencies is another possibility where and when this is permitted. Ideally, a segregation of frequency utilization into sub-bands offers much more protection as compared to situations where frequencies assignments are interlaced. IM may be generated, but it is more likely to be within ones own sub-band where the system design can mitigate it. IM products generated at the source and outside the sub-band can be filtered.

12.3.2 REDUCE ERP OR SIGNAL STRENGTH OF THE UNDESIRED SIGNAL

One way to reduce interference is to reduce the signal strength of undesired signals. This may be difficult at times as the amount of reduction required may be sufficient as to negatively impact communications on those channels. But when possible, this can be effective solution.

In some cases the reduction may be aimed solely at the sideband energy on a given channel or set of channels. In other cases, a reduction in the radiated power of the main carrier is required.

Adding filters (typically RF cavity filters) between a transmitter and the antenna may by used to reduce the energy radiated in channels separated from the transmit frequency. Cavity filters typically offer little reduction within 150 kHz on either side of the carrier frequency. Cavity filter will typically offer more protection at greater frequency separations. Ceramic autotune cavity filers and combiners provide higher Q filters while offering more flexibility to change frequencies when needed. Note that some autotune cavities may not function with iDEN modulation.

Lowering transmitter ERP can help control both sideband noise levels as well as the power in an IM mix. Due to the nature of IM interference, a 1 dB reduction in ERP on frequencies involved in a 3^{rd} order mix can reduce the IM product level inside a portable receiver front-end by 3 dB. For 5^{th} order mixes, a 1 dB reduction can reduce the IM level by 5 dB. A 1-2 dB reduction in transmitter ERP may be enough to reduce the IM levels to acceptable levels. A reduction in transmit ERP may reduce the size of a cell and the traffic carrying capacity of that cell. A drop in offered load may also allow one or two transmitters to be turned off, thereby decreasing the interference potential of the cell.

ERP can be simply reduced by reducing the transmitter power. This change affects the entire cell. A more selective way to change the ERP to specific location is to change the antenna gain pattern. The area where a reduction is desired may be a specific spot or it may be the area within a certain distance of the site. Reducing antenna gain , reducing down-tilt, or using an antenna with greater lobe reduction or using a different gain antenna can all be used to reduce the signal strength near a site where there is an abundance of signal strength.

There are several more creative ways to reduce IM interference by reducing the levels of the signals involved in the process. A portable with increased immunity against the IM products is one of the best methods of protecting oneself from IM interference no matter what the sources are. Such a portable generally has better all around performance and the added expense is well worth the investment, especially given the growth in wireless and the increased chances of operating near other wireless devices. A portable with an IM spec of 75 dB or greater is sufficient protection against almost all IM in studied and expected scenarios. Receiver specification improvements typically require an increase in battery drain to provide enhanced IM performance. That is why mobile installations tend to have better IM performance than portables.

Oddly enough, using a lower gain antenna on a portable that is experiencing IM interference is one way to lower the amount of undesired signal reaching a portable receiver's front-end. This lowers the desired signal a few dB but reduces the IM products by the order of the product. This can be an effective solution when there is sufficient desired signal strength and the interference is due to front-end overload. Note that a lower gain antenna may reduce the portables' effective range in other situations.

Another method of decreasing the impact of an undesired signal to increase the distance between the source and target. Path loss increases logarithmically with distance. Distance also changes the amount of gain in the antenna pattern. The potential for interference is noticeably reduced when sites are above 80' above ground level (AGL). Raising the center of radiation of transmit antennas can eliminate interference. Zoning rules and atheistic are forcing antennas to lower levels and there may be "stealth" sites behind store-front facades and many more sites below 80' AGL. A more conventional tower or building installation provides increased protection from RFI. Note that increasing demands for wireless services is a factor in more sites that are heavily loaded and frequency reuse is enhanced when theses sites are deployed below tree top or building top levels.

Lowering the ERP's and reducing the number of transmitters on any one site may shrink the coverage area of a given cell and off load traffic to surround cells. Adding additional cells (otherwise known as cell splitting) adjacent to the cell is one way to accommodate these reductions while maintaining offered service levels.

Sweeping sites to find transmitted IM (IM) is required regularly to insure legal operation. Reducing transmitted IM levels and maintaining low radiated IM levels is an effective method to reduce the possibility of interference of this type.

12.3.3 INCREASE ERP OR SIGNAL STRENGTH OF DESIRED SIGNAL

A number of methods exist for reducing or eliminating interference by increasing the desired signal level. This method can override many forms of interference including both Sideband noise and receiver IM.

It is fairly common now for users of wireless communications systems to desire or demand coverage inside buildings. Many two-way radio users conduct business indoors and therefore need inside coverage. The mobility of portables requires in-building coverage. Public Safety users often have to enter buildings to perform their critical life-preserving activities. Providing in-building coverage will require more sites or equipment but it will also provide protection against many forms of interference. Many of the interference problem areas can be found near other sites while on the street. The little extra building loss usually reduces the interference down below troublesome levels. This is especially true for the case where IM is occurring in the portable's receiver. Every dB of attenuation to the undesired produces a 3 times or 5 times reduction in the level of any IM product.

Increasing the transmitter power on desired frequencies can improve the downlink performance by overriding the interference. The ERP can also be raised into a particular area by changing the antenna pattern or by increasing antenna gain. Increasing the antenna height above ground level on the desired transmitters can also increase the level of the desired signal.

Adding additional sites on the desired channels is another available option. This has the added benefit of increasing coverage inside buildings.

Deploying Bi-Directional Amplifiers (BDA) or channelized repeaters are also possible ways to improve coverage into specific areas that would benefit from enhanced coverage. However, BDA's can be a source of interference so their deployment needs to be well engineered.

The co-location of transmitter sites ensures that the desired signal is stronger on-channel than any interfering signal. This may not always be possible when mixing systems of different types such as high density cellular on many low sites and a lower density two-way radio system on a few high sites. This option reduces talk-out interference but it can increase talk-in interference, requiring "voting" receivers to minimize this effect.

Mentioned above, the use of a portable with higher performance specifications is another way to reduce the probability of interference. The specifications of interest are the selectivity and IM performance of the radio. Radios with specifications in this areas > 70 dB are needed to offer reasonable protection for use in typical environments where there high levels of desired RF. Increased protection is offered by improved specifications.

Increasing the signal strength of the desired signal is a highly effective method for minimizing interference and these choices should be considered as alternatives in most cases.

12.3.4 LONG TERM AVOIDANCE

Longer term strategies for minimizing or eliminating inference may involve an exchange of frequencies or a segregation of frequencies to move the operations of any given system to its own spectrum allocation. This will usually require some approval by the FCC and possibly some coordination with one or more designated coordinating bodies.

Swapping one or more frequency pairs may provide an opportunity to address an individual case or set of cases throughout a small area.

Segregating frequencies would separate distinct service types into different sub-bands and offer higher each service a higher level of protection against interference. There may be some interference if the sub-bands are located next to each other but the interference in such cases would easier to predict, identify and create an engineered solution when it does occur.